***"Irrigation Systems: Overview about Technology & Management Results of Experiments on Drip Irrigation in Egypt"***

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## *DEDICATION*

To soul of my father; Abdel-Fattah Hemdan Mohamed,

To soul of my sister; Hala,

To my mother; Ebtsam Mohmoud Ali Sultan,

To my brothers and my sister; Mohamed, Ahmed and Heba,

To my nephews and nieces; Eman, Prence, Remas and Islam

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| | |
|---|---|
| €: Euro (currency) | UN- Comtrade: United Nations Commodity Trade Statistics Database |
| $CO_2$: Carbon dioxide<br>cm centimetre | UNDP: United Nations Development Programme |
| $ET_0$ : Reference crop evapotranspiration | WAE: Water Application Efficiency |
| $ET_c$: Crop evapotranspiration | WE: Water Economy |
| FAO: Food and Agriculture Organization of the United Nations | WHC: total water holding capacity |
| FC: Field capacity | WP: Wilting percentage |
| fed.: feddan =4200 $m^2$ = 0.42 ha. | WS&S: The water supply and sanitation |
| FUE: Fertilizer use Efficiency<br>g gram<br>GECID: German National Committee of ICID | WUE: Water Use Efficiency |
| GHG emissions: Greenhouse-gas emissions | |
| ha.: hectar = 10000 $m^2$ | |
| IPCC: The Intergovernmental Panel on Climate Change | |
| K: Potassium | |
| $K_c$: Crop coefficient | |
| kg: kilogram | |
| L.E.: Egyptian pound (currency) | |
| m: meter | |
| MALR: The Ministry of Agriculture and Land Reclamation | |
| me/l: milliequivalent per litre | |
| MHUNC: The Ministry of Housing, Utilities and New Communities | |
| MWRI: The Ministry of Water Resources and Irrigation | |
| N: Nitrogen | |
| NP: Net Profit | |
| P: Phosphorous | |
| UN: United Nations | |

## *1. INTRODUCTION*

Water is essential for socio-economic development and for maintaining healthy ecosystems. As population increases and development calls for increased allocations of groundwater and surface water for the domestic, agricultural and industrial sectors, the pressure on water resources gets intensified, leading to tensions, conflicts among users, and excessive pressure on the environment. Scarcity often has its roots in water shortage, especially the arid and semiarid regions affected by droughts and wide climate variability, combined with population growth and economic development, where the problems of water scarcity are the most acute.

Water usage has been raising as much as more than twice the rate of population increase in the last century. The number of regions that suffered chronically short of water had increased. By 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under stress conditions. The situation will be exacerbated as rapidly growing urban areas place heavy pressure on neighbouring water resources (Riesbeck, 2008).

Although there are many sources of water consumption, irrigation remains the main water user on a global scale. However, there is an increasing pressure on agriculture to use water in a more efficient manner. On the contrary, irrigation is regarded as one of the main ways to increase food production and incomes. It is therefore crucial to enhanced water management in order to achieve both high water productivity and higher income (FAO, 2006).

Due to the limited water resources, which necessary for reclaiming more areas of desert to produce more food, some modern techniques must be used. Drip irrigation represents one of the most spreading systems in the new reclaimed areas. It has the ability to raise the efficiency of irrigation water, by reducing water losses via evaporation, saving water in root zone and hence preventing it from loss by percolation, and ultimately, increasing water use efficiency (Boodt et al, 1990 and Shock, 2000). Valenzuela (2001) stated that drip irrigation efficiency ranged from 75-95% compared to 25-50% of surface irrigation and 75-80% and 65-75% of soiled set and portable sprinkler system respectively. On the other hand rationalization of irrigation water can be achieved through the use of organic composts resulting from recycling farm wastes by a process known as composting. A study carried out by Zebarth et al. (1999) proved that sandy infertile soils can benefit from the addition of organic waste materials that increase soil organic matter content, decrease bulk density, and increase soil water retention of coarse soils.

The better soil and water management under drip irrigation system is an addition to organic soil conditioners, in combination with straw mulching and some developed agricultural methods. El- Sedfy (1998) indicated that incorporating organic manure with the soil in the surface soil layer passively affected on the aggregates formation and increased the tomato and potato yields under drip irrigation system. Also the natural soil conditioners decreased the soil bulk density, infiltration rate and the hydraulic conductivity while increased the stable soil aggregates and total soil porosity in sandy soil. It was found that crop productivity and water use efficiency increased under drip irrigation, especially when the soil treated with organic amendments where hydrophysical properties and nutrient status of the soil were improved (Gawish, 1985).

With respect to mulching method, Renquist et al. (1982) found that drip irrigation associated with mulching, led to the highest yield and the greatest water use efficiency. Oster et al. (1986) reported that mulching affects the salt distribution pattern in the soil, reduces the surface evaporation and decreases the accumulation of salts in the root zone. Also, Gicheru et al. (2004) reported that manure and surface mulching should be taken into account in land management and water conservation as they increase steady infiltration rates and amount of soil water stored in the soil and better drainage.

A complete package of water regimes under drip irrigation, mulch and compost will save irrigation water under desert conditions and increase exported potato crop which represent a vital goal of this study.

## *2. REVIEW OF LITERATURE*

### *2.1. <u>The most important phenomena affecting food security:-</u>*

Increasing the safe production and nutritious supplies for food represents a big challenge for agriculture sector to meet increasing world demand while maintaining the environment (Shepherd et al., 2011). There should be efforts to achieve sustainable development in agricultural production. Poverty causes undermining health and the environmental degradation. Environmental problems link the agricultural and health research agendas. Hence environmental changes at the global level will require improvements in both food production and health practices. (Ruttan et al., 1994).

In the future, there will be also major challenges resulting from the rapid change in socio-economic environment that threatens current and future efforts to achieve food security and survive undernourishment. This refers to the following: a) increase in world population; b) urbanisation; c) dietary changes; d) climate and global environmental change and the consequent loss of ecosystems; e) using food crops as a source of bioenergy and therefore f) the food and financial crises. Sustainable agricultural development is essential to achieving food security; it could be act in four ways: to increase in agricultural investments, improvement of global trade, increase in food productivity and the conservation of natural resources (Bohle et al. 1994 and Parry et al., 1999; Tirado et al. 2010b; Ruane and Sonnino, 2011).

#### *2.1.1. <u>Climate change</u>*

The relative importance of climate change that affects food security differs between regions (IPCC, 2007). FAO (2008) reported that the impacts on food, water security and nutrition included:

- Increased frequency of extreme climatic events.
- Sea-level rise and flooding of coastal lands, leading to salinity and/or contamination of water and agricultural lands; these changes will in turn cause deterioration of existing ecosystems. For example, rising water level of the Mediterranean Sea affected vegetation and farming in the region (Gahukar, 2009).
- Impacts of temperature increase and water scarcity on plant or animal physiology.
- Beneficial effects to crop production through $CO_2$ (fertilization).
- Influence on plant diseases and pest species and livestock diseases, leading to crop and animal losses.

-Damage to forestry, livestock, fisheries and aquaculture.
-Impaired sustainability: socio-economic, political/armed conflict and demographic impacts.

There are many pathways through which global climate change and variability may impact environmental contamination and chemical hazards in foods. These hazards can arise at various stages of the food chain, from primary production to consumption; climate change may affect food systems in several ways ranging from direct effects on crop production to changes in markets, food prices and supply chain infrastructure (Tirado et al., 2010a; Gahukar, 2009; Gregory et al., 2005; Reilly et al. 1994).

Anthropogenic climate change does not only affect water resources but also water demand, consequently, future water and food security will depend, among other factors, on the impact of climate change on water demand for irrigation (Döll, 2002). Recent global temperature increases have been the highest in the last century (IPCC, 2001) accompanied by a widespread reduction in sunshine duration (Stanhill and Cohen, 2001). On the other hand, predicted increases in solar radiation, and wind speed under doubled concentrations of atmospheric carbon dioxide ($CO_2$) are likely to alter plant growth and harvestable yield through a mixture of climatic and $CO_2$ fertilization effects as well as impacts on plant water demand (Allen and Rosenzweig, 1991; McCarl et al., 2001).

Furthermore, all soil processes will be strongly impacted, in the interplay of the soil and the atmosphere, the soil can be both a contributor to and a recipient of the impacts of climate change; microbial decomposition is stimulated by higher temperatures so availability of soil nutrients and organic matter which helps hold the soil moisture may be negatively affected by higher temperatures. The use of good land management practices provides the best strategy for adapting to the impact of climate change on soils; the task of soil management should be to restore soil organic carbon in order to enhance soil structure and fertility and to help to counter the atmospheric greenhouse effect (Rounsevell et al., 1999; Rosenzweig and Hillel., 2000; McCarl et al., 2001).

### *2.1.2.* ***Pollution***

Chowdary et al. (2005) explained that agriculture is the main non-point pollutant of groundwater in irrigated areas as fertilizers and other agrochemicals are the main contaminants in the water that drains out of the root zone to recharge the aquifer. Archambault (2004) found that nitrates from fertilizers are considered the source of pollution. For example, nutrient and pesticide pollution accompanying the intensive agriculture activities of the last fifty years has significantly impacted the Baltic Sea ecosystem in northern Europe.

There are three major ways in which air pollutants may damage agricultural production

1. Direct visible injury, usually to leaf tissue. If extensive, this can affect crop yield, and superficial damage can make the crop look less appealing to consumers, thus lowering its value.
2. Direct effects on growth and yield. Experiments with a range of different pollutants have shown that yields are generally reduced by increasing exposure to pollutants, even in the absence of visible injury.
3. Indirect effects. Even at relatively low levels, air pollutants may cause a range of subtle physiological, chemical or anatomical changes which will not lead to detectable yield reductions under optimal growth conditions. However, these changes may increase the crop's sensitivity to other stresses, thereby contributing to significant yield losses (Marshall et al., 1997).

Increase in fossil fuel use and climate change leads to increase in $O_3$ concentrations to levels that threaten the food supply. However, $O_3$ pollution poses a growing threat to global food security (Teixeira, 2011; Avnery et al., 2011).

#### *2.1.3.* ***Bioenergy***

Bioenergy has been politically promoted as a method to mitigate air pollution, climate change, and scarcity of fossil energy sources, despite global reductions in food production, undernourishment may decrease in certain locations (Schneider et al., 2008).

Possible negative environmental impacts include increased nitrous oxide emissions (Crutzen et al. 2008) and consequences of emission leakage through agricultural intensification and expansion into native forests (Gielen et al., 2003). Bioenergy production may generate additional income and employment opportunities in the agricultural sector (Panoutsou, 2007). Land rents and wage rates are likely to increase (Schneider et al., 2008).

However Cohen et al. (2008) showed that biofuel production can lead to undernourishment through three basic factors: increased GHG emissions, direct effects on health and sanitation and reduced food availability and increased its price. Increase in bioenergy consumption in areas requiring further irrigation water from already depleted aquifers could cause growing water scarcity problems and rise in cereal prices.

Although biofuels are considered a new source of demand for some crops, agricultural development and profit growth, it could also lead to food insecurity. Agricultural markets are continuously responding to changes in demand and supply, therefore the biofuel production may have probable impact on commodity markets (FAO, 2010b).

### *2.1.4. <u>Water Scarcity</u>*

The decrease in water per capita, the transfer of water from agriculture to other sectors, and the shift from food crops to higher-value crops may in combination have a negative impact on the food security. Water deficit stress may be resulted in climate change as precipitation can not sufficiently compensate for an increased evaporative demand due to a temperature rise. This stress could lead to decrement in yield or increment in the irrigation water amount to maintain yields Small and marginal farmers will have to be assured of food security through increasing productivity of their lands. Both have to be achieved while simultaneously maintaining ecological sustainability (Haskett et al., 2000; FAO, available online). UN-Water (2007) reported that most countries in the Near East and North Africa suffer from acute water scarcity, as do countries such as Mexico, Pakistan, South Africa, and large parts of China and India. Irrigated agriculture represents the bulk of the demand for water in these countries. It is also usually the first sector affected by water shortage and increased scarcity.

Riesbeck (2008) summarized the problems of water use as follows:-

- No sustainable using of water resources and inadequate water supply and waste water management of billions of people have been fatal consequences in some countries.
- Most of diseases in developing countries connected with polluted water.
- More than 30 countries in Africa, Middle East and Asia have scarcity of water.
- Bad water supply is a reason for non-industrial development in some countries; potential investors prefer investing in other countries with a better resource situation.
- The Agriculture has been now using 70 to 90 % of freshwater in developing countries.
- Environmental problems through the unofficial agricultural water using are grown up: 20 to 30 % of all irrigated areas have problems with salinity and erosion.

Policies and practices of irrigation water management under water scarcity must focus on specific objectives according to the causes of water scarcity. Pereira et al. (2002b) indicated that aridity is very often associated with high pressure on natural resources, strong competition for water that aggravates the limiting resource for agriculture, frequent soil salinisation due to poor management of irrigation, and vulnerable and fragile ecosystems.

### *2.2.* ***<u>Irrigation systems: Technology and management</u>***

Water management is an important element of irrigated crop production. Efficient irrigation systems and water management practices can help maintain farm profitability in an era of limited, higher cost water supplies. Efficient water management may also reduce the impact of irrigated production on off-site water quantity and quality.

It is important to have a good method for both irrigation scheduling and management in order to achieve the maximum production and minimum environmental impact (USDA, 2006; Christen et al., 2006). Water management plan for each crop is crucial factor for maintaining a regular, consistent supply of soil water to 1) obtain optimal irrigated crop growth, 2) improve product quality; 3) reduction in seasonal growth and yield variability and 4) support irrigation management to provide multiple advantages resulting from water savings and increasing sustained profitability.

The efficient irrigation supplies management that leading to water savings are considered a crucial matter for meeting future water needs for agriculture and other uses (Wright et al., 2004; USDA, 2006).

#### *2.2.1.* ***<u>Choosing irrigation system</u>***

FAO (1988) showed that to choose an irrigation method, the farmer must know the advantages and disadvantages of the various methods. The suitability of the various irrigation methods, i.e. surface, sprinkler or drip irrigation depends mainly on the following factors: natural conditions, type of crop, type of technology, previous experience with irrigation, required labour inputs, costs and benefits. Sprinkler and drip irrigation may be more appropriate in case of steep or irregular slopes, soils with a very high infiltration rate or scarcity of water.

Lecina et al., (2010) reported that traditional surface irrigation systems and modern sprinkler systems currently occupy 73% and 27% of the irrigated area in Spain, respectively. Virtually all the irrigated area is devoted to field crops. Sprinkler irrigation is preferred due to the lack of labour and the reduction of net incomes as a consequence of reduction in European subsidies, among other factors.

### *2.2.2. Use of Improved Irrigation Technology and Management*

Water scarcity is a growing concern for sustainable agriculture worldwide. Therefore, many nations have attempted to reform water management systems by improving irrigation systems. Turral et al. (2010) mentioned that there are powerful implications of global climatic change on irrigation through changes in hydrology and water supply. Improvements in irrigation performance and the productivity of agricultural water use are likely to become more targeted at higher value enterprises. Constant adaptation is required for improving irrigation management via better institutions and technology.

Reduction in production costs, water savings and reduction of nutrient leaching can be obtained through improving irrigation management (Simonne et al., 2004). Enhancement of efficient applied water in agriculture can be obtained through various management practices and modern technologies. Upgrading physical application systems is necessary for irrigation improvements that will be reflected on improved field application efficiencies and higher yield potentials (USDA, 2001).

Furthermore, the improvement of the irrigation method and the system performance requires the consideration of several factors mainly those influencing the hydraulic processes, the water infiltration and the uniformity of water applied to the entire field (Pereira et al., 2002a). Potential for improving water use efficiency depends on the degree of understanding of the crop and soil system, the flexibility in management offered by the irrigation system and water supply, and the sensitivity of yield-determining factors in providing an economic response to improvements in water management (Christen et al., 2006).

### ***2.2.3. The automated system using modern irrigation technology***

There has been a growing realization of possible improvement in water management for a more efficient use of available water resources. The potential of information technology applications for improved irrigation system management was realized. Using computers, communication and information to control irrigation systems will yield many benefits, resulting in obvious economic savings and in intangible benefits whose value cannot be measured in monetary terms (FAO, 1999).

Bravdo et al. (1992) found that a computer controlled automated irrigation and fertilization system which consists of soil matric potential sensors located in the main root zone was developed. This system provides a means for controlling the size of the root system as well as the root environment. An increase in yields and in fruit quality was obtained in a few fruit tree species during field experiments. Irmak et al. (2001) reported that automatic soil water sensor-based irrigation seeks to maintain a desired soil water range in the root zone that is optimal for plant growth.

In a previous experience working with a soil-moisture-based automatic irrigation system, Dukes et al. (2003) found that once such a system is set up and verified, only weekly observation was required. High frequency irrigation events based on soil moisture sensor control can maintain crop yields while reducing irrigation water requirements. Boutraa et al., (2011) showed that this type of system adapts the amount of water applied according to plant needs and actual weather conditions throughout the season. This translates not only into convenience for the manager but into substantial water savings compared to irrigation management based on average historical weather conditions.

An automatic irrigation control system is a potential solution to optimize water management by sensing soil water conditions and site-specifically controlling irrigation sprinklers. Recent technological advances have made soil water sensors available for efficient and automatic operation of irrigation systems (Dukes et al., 2005).

In addition, an automated system using modern irrigation technology is not only more efficient at getting water to the plant it also saves many hours in basic labour. However, the benefit most owners fail to realize is the reduction in management time devoted to irrigation. Determining when and how much irrigation water to apply is an important part of the irrigation management process (Thomas, 2005).

Peters and Evett (2006) showed that the automated system applies irrigations when needed by the crop and produces yields and water use efficiencies that are as good as the best scientific irrigation scheduling method. The automated system reduces farmers; management time and labor and is fully compatible with the control panels on current centre pivot irrigation systems.

Selection of controller type depends upon a number of factors: 1) level of automation required; 2) power source availability; 3) number of station to be irrigated and 4) location of the controller. For irrigation systems that have to be expanded over a period of time, then it may be more cost effective to install a controller with enough stations for the final system, or install a controller that allows for modular expansion. This also requires the need for provision for wiring for the final system. The basic function of a valve is to operate ‘gates’ to control the flow of water through the lateral lines (Netafim, available online).

### 2.2.4. *Management of drip irrigation systems*

Drip irrigation has a high efficiency for adding water and nutrients to crops. Comparing to sprinkler irrigation, drip irrigation can reduce water use by 50 percent. Crop yield can increase through improved water and fertility management and reduced disease and weed pressure. Thus, the main benefits of drip irrigation are that it reduces water use and improves the health of the plant (Anderson, 1999; Lamont, 2002).

Many factors affecting on proper drip irrigation management, including system design, soil characteristics, crop and growth stage, environmental conditions, etc. The effects of these factors can be integrated into a practical, efficient scheduling system which determines quantity and timing of drip irrigation. This system combines direct soil moisture measurement with a water budget approach using evapotranspiration estimates and crop coefficients (Hartz, 1999).

The target of drip irrigation scheduling is to select an irrigation duration and frequency that results in a properly sized wetted area around plants and keeps the soil in the root zone at or near field capacity. The right schedule for irrigation system depends on specific crop requirements, soil texture, field preparation and weather conditions. Adjustments throughout the season based on monitoring of field conditions permit to fine-tune the irrigation schedule to the crop needs (RO-DRIP® User Manual, 2001).

According to the survey of literature that was carried out by Namara et al.(2005) on impacts of drip irrigation technologies; they are mainly enhanced for one or more of the following objectives: (1) as a means of saving water in irrigated agriculture and averting the impending water crises (Polak et al. 1997; Shah and Keller 2002; Narayanamoorthy 2003), (2) as a strategy to increase income and reduce poverty among the rural poor, (3) to enhance the food and nutritional security of rural households (Bilgi, 1999; Upadhyay, 2003; Upadhyay, 2004), and (4) as a means to extend the limited available water over a larger cropped area. Drip irrigation technologies lead to poverty reduction through substantial increases in farm income due to an increased area of cultivation, better crop yields, enhanced output quality, early crop maturity and hence higher unit prices, and reduced cultivation costs, particularly for operations like irrigation and weeding.

#### 2.2.4.1. *Drip irrigation System maintenance*

Plugging is the mainly serious risk to a drip irrigation system and arises from physical, biological, and chemical contaminants. The filter is the core of the system. Keeping it serviceable and clean will prolong the life of the drip system; the type of filtration system to be used with a drip irrigation system will be dependent upon the source and quality of the water to be used for irrigation. Filtration can remove physical contaminants, and chemical water treatment is often necessary to eliminate or remove biological and chemical contaminants. The drip system filter should be checked daily and cleaned if necessary. A clogged screen filter can be cleaned with a stiff bristle brush or by soaking in water. Sand filters need to be backwashed. Periodic flushing of the mainline, sub-mainline, and drip tape is an excellent maintenance practice (Lamont, 2002; Naan Dan Irrigation Systems (C.S.) Ltd, available online; Netafim, 2008).

Obreza (2004) summarized maintenance drip irrigation system as follows:-

- Preventive maintenance enables a drip irrigation system to operate at peak efficiency and will save water and fertilizer.
- Routinely maintain pumps, power units, filters, valves, pressure gauges, flow meters, and field pipe/tubing/emitters.
- Flushing the irrigation system is critical to prevent emitter plugging.
- A plugged or scaled irrigation system requires remedial maintenance including cleaning or replacing emitters and line purging.
- Water treatment to reduce emitter plugging potential may include chlorination, acidification, and/or injection of scale inhibitors and sequestering agents.
- The effectiveness of water conditioning or purge chemicals should be evaluated with scale-monitoring devices or water distribution uniformity checks.

### 2.2.5. *Irrigation Water Prices and Costs*

Gollehon and Quinby (2006) reported that irrigation water prices are of considerable interest due to their importance as production cost and their impact on water demand.

Variation of irrigation water cost depends on many factors such as rent combinations of water sources, suppliers, distribution systems, and other factors such as field proximity to water, topography, aquifer conditions, and energy source. They also added that ground water required higher energy costs than the case of surface water.

Changes in global water prices involving higher rates, per unit-water charges, and block-rate pricing may help to induce adoption of water-conserving technologies. However, pricing reform alone is not likely to prompt the level of overall water conservation desired on financed projects (USDA, 2006).

USDA (2001) indicated that substitution of groundwater supplies could limit the public water-price policy on investment in conservation of technologies. Water-price policies could be further efficient when applied in combination with other alternatives of technology choice and crop productivity.

### *2.3. Effect of drip water regimes:-*

#### *2.3.1. Effect of water regimes on water use (water consumption) and water use efficiency*

Mateos et al. (1991) indicated that drip irrigation improved soil water regimes and Water application efficiency was 30% higher in the drip irrigation as a result of increasing crop yields.

Dorota and Forrest (1996) reported that evaporation in drip irrigation system was smaller than other irrigation systems. They also emphasized the need to take the soil physical properties, quality of irrigation water and water requirement of plants in consideration at designing a drip irrigation system and the importance of efficient management of it.

Kang et al. (2004) carried out a field experiment comparing different irrigation frequencies and soil matric potential thresholds on potato evapotranspiration (ET), yield (Y) and water-use efficiency (WUE) in a loam soil. The obtained results indicated that both soil matric potential and drip irrigation frequency influenced potato ET, Y and WUE. Potato ET increased as irrigation frequency and soil matric potential increased. Potato Y increased with the increase in soil water potential then started to decrease.

The implementation of drip irrigation technologies results in net water savings, thereby easing the prevailing water-scarcity problems. The water saving is attained through substantial reduction in losses due to evaporation and inefficient field conveyance and distribution systems. For instance, water application can be reduced by 50 to 100 percent through the drip method of irrigation (Namara et al., 2005).

Onder et al. (2005) investigated the effects of two drip irrigation methods and four different water stress levels on potato yield and yield components. The surface drip and subsurface drip irrigation methods were used. Water use efficiency of surface drip irrigation methods had generally higher values than subsurface drip irrigation methods. Also, Singh (1990) found that using the drip irrigation system led to an increase in the water use efficiency.

Nahla Hemdan (2003) and Gameh et al. (2004) found out the best drip irrigation management that maximized the production of some crops (sorghum, sunflower, faba bean, pea, cowpea and squash) under the Western Desert conditions in Egypt. Obtained results showed that all vegetative growth parameters, yield components and total yield significantly increased by increasing applied water. Obtained optimum water regime which gave the highest water use efficiency was varied according to the type of crop.

Comparing to furrow irrigation, drip irrigation of potato reduced water use, nitrate leaching, erosion, and deep percolation, while increased marketable yield. Drip irrigation used less water than sprinkler irrigation for comparable yield (Shock et al., 2006).

On the other hand Mustafa et al. (2005) mentioned that water use of the potato crop ranged from 490 to 760 mm for sprinkler-irrigated plots and 565–830 mm for trickle-irrigated ones. The highest water use efficiency was 7.37 and 4.79 kg $m^{-3}$ for sprinkle and trickle irrigated plots, respectively.

Kumar et al. (2007) evaluated the role of differential drip irrigation regime on the growth in Punjab, India, during 2002-04, yield and postharvest attributes of potato (Solanum tuberosum) cv. Kufri Chandramukhi. Irrigation for 0.60, 0.80, 1.00 and 1.20 of Ep was applied when cumulative pan evaporation reached 17.50, 13.10, 10.50 and 8.75 mm, respectively. The highest irrigation water use efficiency was observed with the irrigation regime of 0.80 Ep.

Fleisher et al. (2008) revealed that Potato water use efficiency increased with water stress.

Shock et al. (2007) found that best management practices for potato irrigation need to acquire some way to measure $ET_c$ or soil water, or preferably both, along with record keeping to track irrigation, $ET_c$, and soil water. An increase of management applied to potato irrigation can return greater profits to potato growers while enhancing the sustainability of production by avoiding environmental degradation.

***2.3.2. Effect of water regimes on soil properties:-***

Fuller and Moolman (1992) confirmed the importance of understanding the effective root zone for moisture availability and soil water movement with respect to different water flow rates in order to design irrigation systems.

Cooley et al. (2007) showed that to investigate water distribution and movement through potato hills under drip and sprinkler irrigation time domain reflectometry (TDR) probes were installed into potato hills to monitor water content at 15-min intervals at various positions in the potato hill. Water content values in the centre portion of the potato hill, where the greatest densities of roots occur, were greater under drip irrigation than sprinkler irrigation.

Generally, comparing water content values within the centre of the potato hill in both drip and sprinkler irrigation indicated that the values in drip irrigation were greater than the case of the sprinkler irrigation where similar amounts of irrigation water were applied weekly.

**2.3.3. <u>Effect of water regimes on crop:-</u>**

Drip irrigation system is completely suitable for potato production under sandy land conditions, where it can provide the exact water requirements to the crops. This also agrees with the national plan for rationalizing the water use in agriculture. By using drip irrigation system, the optimum amount of water requirements and fertilizer requirements which lead to higher yield, could be added. (Mateos et al., 1991).

Foti et al. (1995) reported that increased water supply increased leaf transpiration, plant fresh weight, tuber growth rate, yield and earliness, and decreased stomatal resistance and tuber dry weight. A higher yield response was obtained at the lower water regimes.

Fabeiro et al. (2001) studied controlled deficit irrigation in a potato crop cultivated in a semi-arid zone (Albacete, Spain). Ten treatments under drip irrigation system were differentiated by the level of implementation of the water requirements. Tuber yield and its components were highly affected by the total amount of irrigation water. The treatments with deficit during the last part of the cycle have had the lowest productions. The larger potatoes were achieved with the treatments which had not suffered deficit in the ripening period. On the other hand, the smallest potatoes were obtained in the treatments with deficit in growth period due to a higher number of tubers per plant. The effect of water on tuber size relies on the combination of deficits during the growth and the ripening stages, through the influence of the number of tubers per plant.

The results obtained by (Attaher et al., 2002) showed that drip irrigation systems had highly significant effect on total yield of potato. The highest yield was 14 ton/fed using surface T-Tape drip irrigation at 125% of $ET_0$.

Zhong Yuan et al. (2003) found that plant height, biomass and shoot water content increased, but the specific leaf weight decreased with increasing amount of irrigation water. The amount of irrigation water had significant effects on decreasing the canopy temperature. Total fresh tuber yields and marketable tuber yields (>85 g) increased with increasing amount of irrigation water. The highest yield was obtained at the 1.25 times regime and the total tuber yield was close to the theoretical maximum. Irrigated water increased yields not only by increasing tuber number, but also by increasing the mean weight of the tubers. Irrigated plots increased potato tuber quantity, but decreased potato tuber quality.

Onder et al. (2005) investigated the effects of surface drip and subsurface drip irrigation methods and four different water stress levels on potato yield and its components. The results indicated that surface drip method had more advantages than subsurface drip irrigation method. Irrigation levels resulted in a significant difference in yield and its components. Water stress significantly affected the yield and yield parameters of early potato production.

Hassanpanah and Benam (2007) noticed that combined analysis of variance showed that irrigation effect on tuber weight (<35mm) per plant, diameter and tuber number was significant. Moreover, Benam and Hassanpanah (2007) showed that water deficit was an important stress factor in potato cultivation and led to yield decrease. The results detected that irrigation treatments had significant effects on tuber yield, tuber number, tuber weight, tuber bigger than 55 mm, and tuber number (35-55 mm). Water stress led to decrease in tuber yield, tuber weight and tuber number (> 55 mm). Tuber-setting stage was the most sensitive stage and led to the most decrease in yield.

Kumar et al. (2007) found that plant height, biomass and tuber yield increased by the increase in irrigation level. The highest tuber yield was obtained in the irrigation regime of 1.20 Ep (Pan Evaporation). A preferable grade of tuber (>28 mm in size) decreased with the decrease in irrigation level from 1.20 to 0.60 Ep. Specific gravity and starch percentage in tuber increased with the increase in irrigation level. Therefore, it could be detected that potatoes should be irrigated at 1.20 Ep to obtain higher yield and better quality. However, if water availability is limited, 0.80 Ep would be most appropriate for sustainable agriculture.

Kumar et al. (2009) compared the effect of micro sprinkler, drip and furrow irrigation systems on potato production. The highest total tuber yield (31.60 ton/ha) was obtained with micro sprinkler, then drip (29.83 ton/ha) and furrow (22.6 ton/ha) irrigation systems when irrigation level was 1.20 IW (Irrigation Water): CPE (Cumulative Pan Evaporation). Potato tuber yield increased with increasing irrigation level from 0.60 to 1.20 IW: CPE, regardless of irrigation system. However, the highest water use efficiency was recorded by 0.80 IW:CPE under micro sprinkler irrigation. Applying 257 and 261 mm of irrigation water attained the best tuber yield under micro sprinkler and drip irrigation systems, respectively.

Nasseri and Bahramloo (2009) noted that initial growth stage is not sensitive to early-season water stress, therefore 51 days produced the highest yield of 30.28 ton and extra-application of water caused a decrease in yield. Consequently, control condition produced the lowest yield. Applying fourth irrigation at the 51 and 59 days after sowing respectively resulted in yield increase as 11.28 % (the highest) and 2.50% (the lowest) relative to that of 36 days after sowing.

On the other hand Mustafa et al. (2005) mentioned that maximum yields were obtained with about 17% less water in the sprinkler method as compared to the trickle method. On the loam and sandy loam soils, tuber yields were reduced by deficit irrigation corresponding to 70% and 74% of evapotranspiration in sprinkler and trickle irrigations, respectively.

### *2.4.* ***Effect of soil mulching:-***

Public interest in organic soil amendments is accompanied by confusion between mulches and composts. Strictly defined, mulches are materials applied across the soil surface; composts are humus-like products of an engineered process (Stratton et al., 1995). Soil-amending mulches and composts are derived from organic (carbon – containing) materials that are more readily decomposable than plastics, and that when partially decomposed or stabilized impart humus to the soil.

Stratton and Rechcigl (1998) illustrated that mulches have many functions in soil application (Table 1). Conservation of moisture by suppressing evaporation from the soil and increasing infiltration of water into the soil are principal functions of mulches. Weed control, temperature regulation, erosion protection, decoration, and to smaller extents insect control, disease control, and plant nutrition are also important functions of mulches. Composts as mulches can serve all of those functions, but usually they are incorporated into soil for improving soil fertility, principally through additions of plant nutrients and organic matter.

**Table (1): Functions and actions of mulches***

| Function | Action |
|---|---|
| **Moisture conservation** | Evaporation is suppressed, and infiltration of water is enhanced by layer of mulch. |
| **Soil temperature** | Heat transfer from solar radiation is reduced in summer; roots may be protected from cold air temperatures in winter. |
| **Weed control** | Layer of mulch is too thick or too impenetrable for weed seedlings to emerge. |
| **Disease control** | Mulch is a protective layer between soil and plants, preventing disease transmission to plants, keeping produce off soil, or suppressing disease growth in soil by competition by mulch-borne microorganisms. |
| **Insect control** | Mulch layer acts as a barrier to insects keeping adults from entering soil or laying eggs on or near base of plants. Light coloured mulches may repel insects. |
| **Plant nutrient** | Plant nutrients from thick organic mulches are leached into the soil. |

*Stratton and Rechcigl (1998)

### 2.4.1.*Effects on Soil Properties:*

Mulches are beneficial to crop production through soil and water conservation, weed control, improved soil structure, higher infiltration and retention of water, stabilization of temperatures and enhanced biological activity (Table 1).

Soil moisture under mulch is increased through the processes of minimizing soil surface evaporation (Himelick and Watson, 1990). Straw mulch increased infiltration rate and decreased evaporation (Tindall et al., 1991).

In general, bulk density of the soil will be lower under mulched than with non-mulched soils (Tindall et al., 1991). Much of the effect of mulches on soil structure may be imparted to the soil as the mulch decomposes and becomes more humus-like.

Surface residues can reduce soil erosion by increasing the size and stability of wet or dry soil aggregates (Layton et al., 1993).

Edwards et al. (2000b) studied the effect of mulching on soil loss from potatoes grown on standard erosion plots. They noticed that on the erosion plots, soil loss with mulching was half of what it was without mulching; and soil water retention was 5% greater with mulching.

Rahman et al. (2005) noticed that rice straw mulching had a significant effect on conservation of initial soil moisture and reduction in weed growth. In addition that mulch treatments were equally effective at conserving soil moisture. As well, Deng et al. (2006)

mentioned that mulching with crop residues during the summer fallow can increase soil water retention.

Chakraborty et al. (2008) showed that mulching is one of the important agronomic practices in conserving the soil moisture and modifying the soil physical environment. They evaluated the soil and plant water status in wheat under synthetic (transparent and black polyethylene) and organic (rice husk) mulches with limited irrigation and compared with adequate irrigation with no mulch. Though all the mulch treatments improved the soil moisture status, rice husk was found to be superior in maintaining optimum soil moisture condition for crop use. The residual soil moisture was also minimum, indicating effective utilization of moisture by the crop.

Materechera (2009) determined that the application of soil amendments, especially mulch, significantly increased the soil water content and this was associated with lower soil penetration resistance. There were significant improvements in soil aggregate properties in the amended soil over the control. Both aggregate size distribution and wet aggregate stability showed significant differences between the amendments.

### *2.4.2.* ***Effect of soil mulching on crop***

Shrivastava et al. (1994) revealed that drip irrigation plus sugarcane trash mulch scheduled at 0.4 PE level was the best combination, which gave the highest fruit yield of about 51 ton ha$^{-1}$ with 44% water saving. 95% reduction in weed infestation was observed when compared with the surface flood without mulch.

Manrique (1995) observed that mulching increased potato tuber yields in mulched plots in the tropics.

Feng (1999) reported that combined with nitrogen, phosphorus and potassium fertilizers, mulching of residues can improve wheat yields by at least 1500 kg ha$^{-1}$. Rahman et al. (2005) noticed that root length density and root weight density of wheat were positively influenced both by rice straw mulching and nitrogen levels. Also mulch treatments were equally effective at suppressing growth of weed flora and promoting root development and thereby improved grain yield of no-till wheat.

Concerning the plant nutrition, Rahman et al. (2005) noticed that nitrogen uptake and apparent nitrogen recovery of applied nitrogen fertilizer were higher in rice mulch treatments. Also mulch treatments were equally effective at conserving soil moisture, suppressing growth of weed flora, promoting root development and thereby improved grain yield of no-till wheat.

Kar and Kumar (2007) stated that application of straw mulch significantly increased the available phosphorus and potassium in the soil.

Also, Kar and Kumar (2007) reported that higher tuber yield and better crop growth were observed in the mulched plots, which might be due to conservation of soil moisture and reduction of soil temperature by 4-6 degrees C. Tuber productions differed significantly among irrigation treatments in the non-mulched plots but they did not in the mulched plots with three and four irrigations.

Wang et al. (2009) determined that potato tuber yield was higher with plastic-covered ridges than bare ridges, and also higher with gravel-sand-mulched furrows than bare furrows in most cases, or straw-mulched furrows in some cases. This was most likely due to decreased evaporation with plastic or gravel-sand mulch.

Yan Hou et al. (2010) found that tuber yield demonstrated benefit from early plastic mulching. Mulch cover for 60 days was favourable for potato production compared to potatoes grown without mulch.

### *2.4.3. **Effect of mulch on water use efficiency***

Shrivastava et al. (1994) detected that drip irrigation plus sugarcane trash mulch scheduled at 0.4 level of pan evaporation was the best combination. The highest yield of 163 kg/ha/mm of water used was also maximum in this treatment. 53% higher yield and 44% saving in irrigation water were obtained when compared with the surface flood without mulch.

Mulching increased water use efficiency in plots that were irrigated every 8 days (Manrique, 1995). Rahman et al. (2005) noticed that mulch treatments were equally effective at conserving soil moisture.

Deng et al. (2006) mentioned that mulching with crop residues can improve water use efficiency by 10–20% through reduced soil evaporation and increased plant transpiration.

Kar and Kumar (2007) stated that water use efficiency was recorded in the mulched plots compared to the non-mulched plots under the same irrigation treatments. Water use efficiency differed significantly among irrigation treatments in the non-mulched plots but they did not in the mulched plots with three and four irrigations.

Wang et al. (2009) determined that WUE for potato was higher with plastic-covered ridges than bare ridges, and also higher with gravel-sand-mulched furrows than bare furrows in most cases, or straw-mulched furrows in some cases. This was most likely due to decreased evaporation with plastic or gravel-sand mulch.

Yan Hou et al. (2010) found that mulch reduced irrigation water required and evapotranspiration; however, extending mulch duration beyond 60 days had little effect on evapotranspiration. WUE demonstrated benefit from early plastic mulching.

### *2.5. Effect of compost*

Perez Piqueres et al. (2006) stated that soil organic matter is considered as a major component of soil quality because it directly or indirectly contributes many physical, chemical and biological properties. Thus, soil amendment with composts is an agricultural practice commonly used to improve soil quality and also to manage organic wastes.

#### **2.5.1. *Effect of compost on soil properties:-***

Tester (1990) found that Compost significantly reduced bulk density, increased soil water content, and modified pH to greater depths. Specific surface area of the soils increased linearly with the addition of compost.

A mature compost is an excellent source of organic matter, enhancing the physical (e.g. lower bulk density and increased water-holding capacity), chemical (like slow release nutrients) and biological (supplying a rich diversity of microflora) attributes of the soil (Magdoff, 1992). Mc Burnie and Mitchell (1993) suggested that applying compost from potato waste and cow manure improved moisture and holding capacity of the soil as well as decreased losing chemical by leaching.

Sabrah et al. (1995) indicated that the soil physical properties were significantly associated with the results obtained for straw, grain and protein yields of wheat. Multiple regression analysis revealed that the degree of aggregation is the important soil property for wheat production in sandy soils.

Bazoffi et al. (1998) investigated effects of compost application on various soil physical parameters and soil erosion in three years. Obtained result indicated that compost had a positive effect on soil bulk density for the first year after application. In the following years, the effects were less pronounced.

Abd-El Moez et al. (1999) pointed out that soil structure was improved through the increase in aggregates > 0.25mm and mean weight diameter of size fractions of water stable aggregates. Furthermore, the seasonal evapotranspiration values of both fennel and coriander plants was decreased as a result of using various types of used composts (orange residues, sheep manure and water hyacinth) which mixed with the chicken manure at different ratios.

Application of compost to the soil caused a decrease in bulk density. As well, organic carbon was enhanced from 35 to 58% after adding compost (Gingerich, 2000). Sangakkara (1998) and Abd-el-Moez et al. (2001) indicated that addition of crop residues reduced soil bulk density, increased soil organic matter content, cation exchange capacity and total porosity.

Edwards et al. (2000a) evaluated the effect of compost and straw mulching on soil-loss characteristics in erosion plots of potatoes. The results pointed out that compost had no effect on soil loss. Mulching caused decrement in soil loss by almost 50%. Both treatments led to an increase in soil water content by 6–7%. With respect to soil physical characteristics, soil penetration resistance below the root zone was reduced almost 20%. Soil aggregate stability increased 7% by adding compost.

Ebertseder and Gutser (2001) showed that the application of compost improved soil aeration and water infiltration, and reduced erosion liability. Compost application, even on good arable lands, contributed to improve physical soil characteristics, and thus promoted the sustained use of these soils.

Gagnon et al. (2001) indicated that untreated and composted pulp fibre significantly increased soil organic matter content, the C/N ratio, macro aggregation, carbon mineralization, microbial biomass carbon and enzyme activities, but had no effect on its total nitrogen. Untreated and composted pulp fibre promoted microbial growth and activity in a potato soil which was low in carbon content.

Weinfurtner (2001) mentioned that among the influence on chemical properties such as nutrient balance, buffer capacity or pH compost is attributed benefits to physical properties such as: Soil structure and aggregate stability, hydraulic conductivity, infiltration and erosion, field capacity, air balance and soil temperature. Organic matter improved soil pores by formation of soil aggregates especially in sandy soil, in addition to an increase in water storage capacity. Also, obtained results showed that the bulk density of the soil usually decreased by supplying organic matter, which in turn improved status of drainage and aeration. It could be noted that there were positive effects of compost on the water regime of soils.

Pagliai et al. (2004) reported that applying compost and manure improved the soil porosity and the soil aggregation. A better aggregation indicated that the addition of organic materials acted an important role in preventing soil crust formation. Applying organic materials is essential to improve the soil structure quality.

Carter et al. (2004) found that soil properties were influenced by compost addition, time of addition, and crop phase. Incorporating compost in the soil improved its physical properties (bulk density, macro-porosity, oxygen diffusion rate and water-filled pore space). Soil water content at - 0.033 MPa was increased by compost addition in the potato phase, compared to the control. Applying compost in an intensive three year potato rotation provided benefits in both soil physical and biological properties.

Lynch et al. (2005) conducted a field study to consider the benefits of compost use from various sources of perennial forage production. Regarding soil physical properties and soil organic matter, the results indicated that compost treatments alone achieved improvements in soil physical properties (soil bulk density and water content). Also, compost treatments alone affected on soil C: N ratio and considerably increased soil organic carbon concentration.

The results obtained by Wanas and Abd-El Moez (2005) showed that there was a significant increase in total soil porosity, soil drainable pores and soil hydraulic conductivity, versus a significant decrease in soil bulk density and soil capillary pores with the increase in the rate of mixture of industrial food residues compost.

A pot experiment was carried out by Wanas and Omran (2006). Obtained results and statistical analyses indicated significant beneficial effects on water stable aggregates, pore size distribution (drainable pores, Capillary pores, water holding pores and fine capillary pores) under cotton and banana wastes compost which mixed with the soil surface, subsurface and the whole soil.

Hati et al. (2006) found that 100% nitrogen, phosphorus, and potassium (NPK) + farmyard manure (FYM) significantly improved soil aggregation, soil water retention, micro porosity, and available water capacity and reduced bulk density of the soil at 0-0.30 m depth. Greater crop growth under the NPK treatment resulted in increased organic matter content of soil, which improved aggregate stability, water retention capacity and micro porosity compared with the control. The effects were more obvious with the NPK + FYM treatment and at the surface soil (0-0.15 m).

In an Experiment carried out in Egypt by Wahba and Darwish (2008), compost was applied at the rates of 0 (Control) and 20 ton/ feddan /year to sandy soils in order to investigate its potential for improving the soil properties. It could be detected that compost material not only improved the structure of fine-textured soils but created the structure coarse-textured soils as well. The chemical and physical properties of the soils were affected directly by the compost application. The soil structure and the cation exchange capacity were improved, increasing in organic matter content and reduction in calcium carbonate content were occurred due to the applied compost which was rich in humic acid.

Mylavarapu and Zinati (2009) reported that addition of compost reduced soil bulk density significantly to 1.03 Mg $m^{-3}$ and increased soil moisture retention in simulated drier conditions at 1500 kPa to 0.12 $m^3 m^{-3}$ in plots that received only compost at the end of winter growing season. Overall, addition of compost resulted in improvement of both physical and chemical properties of sandy soils.

Calzolari et al. (2009) observed that the influence of organic amendments on soil physical properties was differed according to the considered soil property and to the different soils. Bulk density values were slightly lower than those observed for the control. Different effects were also observed on soil aggregates stability. Soil organic matter improved the physical, chemical and biological properties of the soil.

Sodhi et al. (2009) reported that the application of rice straw compost either alone or in combination with inorganic fertilizers increased the macro aggregate size fractions except for 0.25 – 0.50 mm fraction. Application of rice straw compost at 2 ton $ha^{-1}$ along with inorganic fertilizers increased carbon and nitrogen concentration significantly over control. The carbon and nitrogen concentration increased further when rice straw compost at 8 tonnes $ha^{-1}$ was added.

#### *2.5.1.1.* ***Effect of compost on soil moisture***

Application of compost increased soil water content (Gingerich, 2000). Foley and Cooperband (2002) evaluated the short- and intermediate-term effects of repeatedly amending sandy soil with paper mill residuals and composted paper mill residuals in a vegetable rotation. The results showed that all paper mill residuals treatments increased plant-available water by 5 to 45% relative to the control. There was a significant positive linear relationship between total soil carbon and plant-available water.

Foley and Cooperband (2002) evaluated the short- and intermediate-term effects of repeatedly amending sandy soil with paper mill residuals and composted paper mill residuals in a vegetable rotation. They found that all amended treatments reduced the average amount of irrigation water required for potato production by 4 to 30% and the number of irrigation events by 10 to 90%. There was a clear trend of greater reduction in irrigation requirements with more carbon added.

Zougmoré et al. (2004) found that application of compost improved soil moisture retention in the sorghum-rooting zone (0.00-0.80 m). Compost reduced runoff and increased soil moisture retention. Savabi et al. (2005) reported that compost improves the water dynamics of soil, including water infiltration, percolation, and water-holding capacity. This can reduce irrigation needs, and associated leaching potential.

Pandey and Shukla (2006) investigated the effects of soil organic amendment (composted yard waste) on movement of water in a sandy soil. The results showed that for the same water table depth, soil moisture content in the compost field was higher than the non compost field in the root zone (top 20 cm). The increased soil moisture was attributed to the increased upflux due to increased capillary rise, which was a result of increased organic matter content of the soil from compost application. As well, Wanas and Omran (2006) mentioned that soil available water increased under cotton and banana wastes compost which mixed with the soil surface, subsurface and the whole soil.

Carter (2007) evaluated the effect of applied compost on soil water retention and available water capacity, and other associative soil properties in a long-term 3-yr potato rotation established on a fine sandy loam. In comparison to the barley phase, a combination of compost and surface tillage in the potato phase was associated with improved soil porosity parameters and increased soil water contents at -33 kPa (field capacity), -100 and -300 kPa. matric potential, compared with the no-compost control.

Thompson et al. (2008) noticed that moisture holding capacity increased with the proportion of compost and followed the order of mixtures containing sand and compost only> mixtures containing sand, compost, and sandy soil > mixtures containing sand, compost, and silt loam soil. Moisture holding capacity was linearly related to the ratio of sand/compost in the mixture. Reductions of compost and additions of soil decreased saturated hydraulic conductivity.

### 2.5.2. Effect of compost on crop

Kulakovskya and Brysovskii (1984) found that the optimum combination rates of organic and mineral fertilizer gave the high potato tuber yield. Also this combination improved potato quality.

Sabrah et al. (1995) found that the manure stimulated suitable conditions for plant growth and acted as a good substratum for microbial activity. Generally, 33·0 ton $ha^{-1}$ of the manure was considered to be the optimum application rate under the environmental conditions of the central sector of Saudi Arabia, El-Gassim region.

Kwon et al. (1996) proved that applying composted rice straw increased plant height and number of stems compared to using chemical fertilizer for potato plant. Gent et al. (1998) reported that amending the soil with compost increased vegetative growth and shoot weight more than final tuber yield.

Sangakkara (1998) indicated that the incorporation of organic matter significantly enhanced the growth of mungbean.

Gent (1998) mentioned that the effect of compost on tuber yield was related to the concentration of nitrogen and phosphorus in the leaves. Abd-el-Moez et al. (2001) found that significant positive correlations were obtained between the uptake of nitrogen, phosphorus, potassium, iron, manganese, copper and zinc (N, P, K, Fe, Mn, Cu and Zn, respectively) by pepper plants. Wilson et al. (2003) found that at 6 weeks, plants (three perennial species) grown in 50% or 100% compost generally had higher leaf potassium, phosphorus, and magnesium; similar nitrogen and Calcium; and lower magnesium, iron, and Aluminium content than plants grown in the 100% peat-based medium. Plants grown in media amended with compost generally produced similar or slightly smaller plants (stem weight, leaf weight, and stem length) than when grown in peat-based media.

Acharya and Kapur (2001) revealed that potato tuber yield under treatment 10 tonnes/ha farmyard manure + 10 tonnes/ha eupatorium compost was similar to that recorded under both levels of nitrogen + 20 tonnes/ha farmyard manure, showing possibility of 50% substitution of farmyard manure with eupatorium compost. Pine-needle mulching maintained higher soil and plant water status, more roots and saved nitrogen equivalent to 60 kg/ha over no-mulch treatment. The practice also saved irrigation and gave about 50% higher yield of autumn and 22% higher tuber yield of spring crop.

Carter et al. (2004) found that compost increased soil particulate organic matter in the potato and barley phases. Compost addition increased potato tuber yield above the maximum yield obtained with nitrogen application. Overall, compost application in an intensive three year potato rotation provided benefits for potato productivity.

Abou-Hussein (2005) established field experiment in newly reclaimed land at El Menoufia governorate in Egypt. Obtained result indicated that the application of compost at a 10 ton/feddan increased the vegetative growth and yield of potato. The interaction between potassium (K) and compost increased the vegetative growth, yield, and quality of potato. Plants supplied with 160 kg $K_2O$/feddan combined with 10 ton compost/feddan produced the highest yield of tubers of superior quality. [1 feddan=0.42 ha]

Hachicha et al. (2006) showed that there was an increase in potato production of 31.5-35.5 ton/ha, compared to 30.5 ton/ha using cattle manure.

Hati et al. (2006) found the greater crop growth under the nitrogen, phosphorus and potassium (NPK) treatment resulted in increased organic matter content of soil. The effects were more obvious with the NPK + farmyard manure (FYM) treatment and at the surface soil (0-0.15 m). Singh and Kushwah (2006) revealed that application of 100% NPK + 30 tonnes FYM/ha resulted in significantly higher tuber yield of 456 q/ha compared with that of other treatments except 100% NPK + 30 tonnes compost /ha and 75% NPK + 30 tonnes FYM/ha. The effect of organic manures (FYM and compost) in combination with inorganic fertilizers was more pronounced compared with that of organic manures alone. Makhan and Khurana (2007) noticed that organic manure 20 ton/ha as well as biodynamic compost achieved even higher yield than recommended dose of NPK. Net return from organic treatments was higher than the recommended dose of NPK.

Pieruccetti et al. (2008) mentioned that compost use in field horticultural crops is an interesting option for recycling organic wastes, with several environmental and economic advantages. It has been shown that compost can improve soil properties and can be an important as a source of plant nutrients.

Maggio et al. (2008) observed that organic farming caused a 25% marketable yield reduction with a higher percentage of large tubers under conventional farming, whereas irrigation increased the marketable yield and the percentage of large tubers.

Mylavarapu and Zinati (2009) showed that soil amended with fertilizer or compost + fertilizer doubled parsley from 15.02 ton $ha^{-1}$ in the non-amended control plot to

30.75 and 32.67 ton $ha^{-1}$ in soils that received fertilizer + compost or fertilizer alone, respectively. In general, addition of compost increased parsley yields.

### ***2.5.3. Effect of compost on water use efficiency***

There was an increase in water use efficiency of plants as a result of application of compost ( Abd-El Moez et al., 1999; Abd-El Moez et al., 2001; Wanas and Abd-El Moez, 2005) .

## 3. THE PROBLEM STATEMENT

Scarcity often has its roots in water shortage, and it is in the arid and semiarid regions affected by droughts and wide climate variability, combined with population growth and economic development, that the problems of water scarcity are most acute. Water use has been growing at more than twice the rate of population increase in the last century (Riesbeck, 2008).

In spite of existing the great Nile River in Egypt, which is the main supply of water. As a result of the growing number of the population and the increasing consumption of water in agriculture, industry, domestic use, etc., Cultivation of desert soils, which make up more than 95 % of total area (FAOSTAT, online 2012), becomes a must to increase the agricultural production. It could be predicted that Egypt will depend on some extent on groundwater to develop the new projects such as Toshky and East Oweinat in the Western Desert (Tahlawi et al., 2008).

The ground water is almost the single water resource at Kharga Oasis ( the capital of New Valley Governorate), the Western Desert in Egypt, is very expensive either for fixed cost of new well which reach as high million Egyptian pound or the running cost which may reach up to 100 thousands Egyptian pound. Hence, guidance and management of irrigation water are a vital for sustainable agriculture in that part of the Western Desert (Nahla Hemdan, 2003).

### 3.1. Problem description

1. The Western Desert is in the arid zone affected by droughts and wide climate variability (Ebraheem et al., 2003).
2. Water scarcity is a main problem in this area; due to the arid climate of the Western Desert of Egypt, groundwater is a most precious natural resource (Aly et al., 2011).
3. The Western Desert area is sandy having poor soil properties (Balba, 1989).
4. The ground water extraction is very expensive either for the digging or the running costs of the well (Nahla Hemdan, 2003).
5. High population growth rates in Egypt where the most of inhabitants are mainly concentrated in the Nile Valley and the Delta as well as in the coastal zone along the Mediterranean Sea (Abdel Kawy and Abou El-Magd, 2012).
6. Although potato crop is one of the most important vegetable crop in Egypt for exportation (Abou-Hussein, 2001), its cultivation isn't common at Kharga Oasis, the Western Desert in Egypt.

### *3.2.* ***Solution:-***

To meet the demand of the growing population in Egypt by producing sufficient food, horizontal expansion should be enhanced thus high management. In the Western Desert, there are many suggested areas for reclamation. These areas are sandy having poor soil properties. Therefore, using natural soil conditioners such as compost and soil mulching has vital importance in solving a numerous of problems of soil.

Ongoing trends of water transfers from agriculture sector can further endanger the food production levels on irrigated lands pushing countries to increasing the food imports in order to meet the local food demands. Drip irrigation has been considered one of the most important methods that have to be applied under the conditions of limiting water resources due to its high application efficiency (Malashkhia, 2003).

Drip irrigation under using organic soil conditioners associated with mulching improves the soil hydrophysical properties and increases crop productivity. This study will focus on soil and water management using compost and mulch under drip irrigation technology in Western Desert, Egypt.

### *3.3.* ***Aim of study***

The present work aims at saving irrigation water and raising water economy and water use efficiency under drip irrigation technology, soil and water management.

The field experiment was carried out at the Agricultural Research Centre Farm,Kharga Oasis, Western Desert in Egypt to evaluate the effect of compost, mulch and water regime under drip irrigation system and their interactions on growth response of potato plant, yield and its components, some soil properties, also determine water consumption, potato crop coefficients, water economy, water use efficiency, fertilizer use efficiency and net profit (net income) for potato local consumption and exportation.

### *3.4.* ***Objectives of study***

1. The objectives concern a reduction of irrigation requirements, the adoption of practices leading to water conservation and savings in irrigation, both reducing the demand for water at the farm, and an increase in yields and income per unit of water used.
2. Achievement the best water economy, water use efficiency for potato crop and irrigation application efficiency for drip irrigation system using compost and soil mulching under different water regimes.
3. Improvement of the soil hydrophysical properties using compost and control evaporation by organic mulching.

4. Calculating water consumption and crop coefficients for potato, compared with reference evapotranspiration.
5. Obtaining some equations, which relate among the parameters under study according to the prevailing conditions in Western Desert, Egypt, which may be applied in other locations that have similar conditions of water, soil and climate.

## *4. MATERIALS AND METHODS*

Realizing the need for water use optimization in the context of water scarcity and increasing agricultural productivity, drip irrigation has been considered one of the most important obligatory irrigation systems, which have to be applied under the conditions of limiting water resources in the Western Desert in Egypt. Furthermore, drip irrigation method has the highest application efficiency among the other methods. Using organic soil conditioners under drip irrigation improves the soil properties, saves irrigation water and increases crop productivity.

The proper soil and water management (water regime, controlling of soil moisture retention and improving soil properties by adding incorporated compost or mulch) requires not only accurate determination of crop water requirements but also water amount of that should be applied to get the output of each unit of water.

This investigation was carried out in loamy sand soil located at Agricultural Research Centre Farm, Kharga Oasis, Western Desert, Egypt (fig.,1), during the winter season 2005-2006.

### *4.1. <u>Soil properties:-</u>*

Location: El-Kharga Oasis, Western Desert, Egypt

Topography: Fairy flat

Erosion: Slight

Drainage: well drained

| Depth | Description |
|---|---|
| 0 – 0.20 m | (10 YR 6/4 moist) light yellowish brown; (10 YR 7/4 dry) very pale brown; single grain structure; some lime segregation. |
| 0.20-0.60 m | (10 YR 5/6 moist) yellowish brown, (10 YR 6/4 dry) light yellowish brown; sandy single grain structure, compact in site, friable in hand, some lime segregation. |

Based on soil taxonomy (USDA, 2010), this soil could be grouped as:

Order: Entisols

Suborder: Psamments

Great Group: Torripsamments

Subgroups:Typic Torripsamments

Table (2) presents the main physical and chemical properties of the soil .Generally, from the aforementioned data, the texture is loamy sand most of its soil separates are non-coherent of organic matter (0.05 %) and other bindery materials (10.56 % clay and 9.35 % $CaCO_3$) is low. The soil is non-sticky, non-plastic when wet and have loose consistency when dry.

The relative distribution of the pore size, which is more important than the total porosity itself, shows that the soil has a large number of large pores which are responsible for good aeration from one hand and rapid movement of water through the soil profile (i.e. rapid loss of water by deep percolation) from the other hand.

Moreover a great portion of the retained moisture is lost at tensions below one bar. Therefore, its available water range (FC-WP) is rather narrow (7.57 %). High infiltration rate (105.0 cm $h^{-1}$) is one of the agronomic obstacle problems of this soil since it increased water and fertilizer losses during fertigation.

The proper soil and water management should be applied to gain the most benefit of this soil. Soil mulching using organic soil conditioners e.g. compost and applying suitable water regime is a must.

### *4.2.* ***Irrigation water characteristics:***

The source of irrigation is a well which was dug in the studied area. Regarding its water quality, it was classified as none problem water.

Analysis of used irrigation water is presented in table (3).

Data presented in the table refer that used water contains 365 mg salt $l^{-1}$. Its pH is slightly alkaline (pH= 7.65). It contains 55.2, 38, 15.6 and 0.08 mg $l^{-1}$ for $Na^+$, $Ca^{++}$, $Mg^{++}$ and $K^+$, respectively. Regarding anions, used water contains 83.8, 170.8, and 25.0 mg$l^{-1}$ for $Cl^-$, $CO_3^{--}$+$HCO_3^-$ and $SO_4^{--}$ in sequence. Moreover, it contains 1.5 mg $l^{-1}$ less than 3 mg $l^{-1}$ $Fe^{++}$. It Adjusted SAR= 2.303. This means that water is classified as none problem water (FAO, 1994).


**Fig. (1): Egypt online map**

**http://store.mapsofworld.com/index.html?main_page=product_info&cPath=19_22&products_id=23474**

**Table (2): Analytical data of the studied soil (before potato crop plantation)**

| Mechanical analysis % | | | | | | |
|---|---|---|---|---|---|---|
| **Sand** | **Silt** | **Clay** | **Texture** | | | |
| **86.0** | 3.4 | 10.6 | Loamy sand | | | |
| **Chemical soil characteristics** | | | | | | |
| **$pH_{1:1}$** | **$EC_{1:1}$ $dS^{-1}$** | **$CaCO_3$ %** | **O.M. %** | **CEC C mol $kg^{-1}$** | | |
| **8.3** | 2.95 | 9.35 | 0.05 | 4.41 | | |
| **Macro-nutrients (ppm)** | | | | | | |
| **Total** | | | **Available** | | | |
| **N** | **P** | **K** | **N** | **P** | **K** | |
| **50** | 335 | 915 | 32 | 27.3 | 80.29 | |
| **Soluble cations (me/l of 1:1 extract)** | | | | **Soluble anions (me/l of 1:1 extract)** | | |
| **$Ca^{++}$** | **$Mg^{++}$** | **$Na^{+}$** | **$K^{+}$** | **$CO_3^{--}$+$HCO_3^{-}$** | **$Cl^{-}$** | **$So_4^{--}$** |
| **8.13** | 7.3 | 15.9 | 2.1 | 0.54 | 23.0 | 8.0 |
| **Hydro-physical analysis** | | | | | | |
| **Bulk density gm $cm^{-3}$** | **Total porosity %** | **Field capacity %*** | **Wilting percentage %*** | **Hydraulic conductivity m $day^{-1}$** | **Water holding capacity %** | **Mean diameter µm** |
| **1.65** | 37.3 | 14.30 | 6.73 | 17.1 | 22.5 | 22.8 |

* On dry weight bases

**Table (3): Chemical analyses of irrigation water used in the experiment:-**

| **EC $dSm^{-1}$** | **pH** | **Soluble Cations (me/l)** | | | | **SolubleAnions (me/l)** | | |
|---|---|---|---|---|---|---|---|---|
| | | **$Ca^{++}$** | **$Mg^{++}$** | **$Na^{+}$** | **$K^{+}$** | **$Cl^{-}$** | **$CO_3^{--}$ +$HCO_3^{-}$** | **$SO4^{--}$** |
| **0.57** | 7.65 | 1.9 | 1.3 | 2.4 | 0.08 | 2.36 | 2.8 | 0.52 |

### 4.3. ***Indicator plant:***

Certified seed potato tuber of cultivar Diamant (locally produced and cold stored), was used in the experiment. Diamant cultivar (fig.2) is medium early to medium late taking in consideration that this cultivar is grown in Egypt for exportation where potato (*Solanum tuberosum L*) is one of the most important vegetable crops grown in Egypt (Annex). Using organic fertilizer in potato production is growing in Egypt now to take place in the European market and to have the consumer who is willing to pay high price for a healthy safe product (Abou-Hussein, 2001).

### 4.4. ***Agricultural practices and cultivation:-***

The regular practices for field preparation were carried out. The whole seed tubers were planted, on $26^{th}$ of October, 2005, at distance 0.25 m between plants and 0.60 m between rows. The tubers were planted in two holes around each emitter on bridges; the plants were thinned to one plant per hole. The plant density was 66668 plants/ha. The crop was harvested on $27^{th}$ of February, 2006.

**Fig. (2): Potato (Diamant cultivar) under drip irrigation**

### 4.5. Description of drip irrigation system:-

The water is managed in the experimental area through farm irrigation system, which supplies water under pressure from the source to distribute it through the irrigable area. The irrigation system consists of the following components (fig.3):

a)Basin for collected water

b) Pump unit

c) Filtration unit (screen filter)

**Fig. (3): Some drip irrigation system components**

-**Basin**, as a source of collected water

-**Head control unit**: pumping, filtration unit and fertilizer device.

-**pipe lines network**:

-Main PVC line of nominal diameter 160 mm / 6 bar.

-Sub-main line of nominal diameter 110 mm / 6 bar PVC pipeline provided with a by-bass arrangement which connects fertilizer injectors.

-Sub-sub-main lines of a nominal diameter 75 mm / 6 bar PVC pipeline.

-Manifold of 32 mm diameter PVC pipeline connected to the sub-sub-main to convey the flow to the laterals. The manifold line length was 30 m.

-Laterals lines of 16 mm diameter PE hoses 25 m length. The used type was (GR) built-in emitter of 4 L/h discharges at 1 bar, and 50 cm emitter spacing. Distance between laterals was 60 cm, therefore:

Number of emitters/ ha =10000 / 0.6 * 0.5 = 33334 emitters

Water supply, ha/ hour = 33334 * 0.004 = 133.33 $m^3$

### *4.6. __Experimental design:-__*

The field experiment was designed as a split-split plot design. The experiment included twenty four treatments which represented the interaction between three water regimes combined with two mulch treatments and four compost treatments. The treatments were arranged in a split-split plot design with three replicates. The water regimes were in the main plot, the mulch treatments were in the sub-plot and the compost treatments were in the sub-sub-plot (fig. 4).

#### *4.6.1. Water regimes (main plot):-*

Taking into consideration potato $ET_c$ requirements are well established and are based on weather data; applied water was estimated using Pan-evaporation and Penman-Monteith method according to meteorological regime in Kharga Oasis during winter season.

-**Using Pan-evaporation**: Pan-evaporation ($ET_{pan}$) is one of the most commonly used climatic measurements to determine the evaporation from natural and managed ecosystems. Since the irrigation was controlled by drip irrigation system, the calculated value of $ET_o$ was multiplied by one third of $ET_{pan}$ (Nahla Hemdan, 2003).

$ET_o$= 428.6 mm, this is equivalent to 4286 $m^3$/ha starting from 26th October until 27th February,

Crop evapotranspiration for potato under drip irrigation $ET_c = ET_o * k_c * k_r$

$ET_c = 429 * 0.80 * 0.9 / 0.85 = 363.4$ mm

-**According Penman-Monteith method** (FAO, 1998): The calculation of reference evapotranspiration ($ET_0$) is based on the FAO Penman-Monteith method. Under Upper Egypt condition, Crop evapotranspiration for potato under drip irrigation: $ET_c$ = 368.8 mm = 3688 $m^3$ / ha.

Mean Crop evapotranspiration for potato under drip irrigation: $ET_c$ =

363.4 + 368.8 / 2 = 732.2 / 2 = 366.1 mm $\simeq$ 400 mm which is equivalent to 4000 $m^3$/ha = 100%.

For above, three water regimes for potato crop were 400 mm, 320 mm, 240 mm (100, 80 and 60 % of $ET_c$ respectively). Relevant amounts of added water such condition were 4000, 3200, 2400 $m^3ha^{-1}$. Table (4) shows the distribution of amounts of water according to potato growth stages where the irrigation intervals were three days.

| | R3 | | R2 | | R1 | |
|---|---|---|---|---|---|---|
| **IW1** | **M0** | **C0** | **M1** | **C3** | **M0** | **C1** |
| | | **C2** | | **C1** | | **C2** |
| | | **C3** | | **C0** | | **C3** |
| | | **C1** | | **C2** | | **C0** |
| | **M1** | **C3** | **M0** | **C1** | **M1** | **C2** |
| | | **C0** | | **C0** | | **C3** |
| | | **C1** | | **C3** | | **C0** |
| | | **C2** | | **C2** | | **C1** |
| | | | | | | |
| **IW2** | **M1** | **C1** | **M0** | **C3** | **M1** | **C0** |
| | | **C3** | | **C2** | | **C1** |
| | | **C2** | | **C1** | | **C3** |
| | | **C0** | | **C0** | | **C2** |
| | **M0** | **C0** | **M1** | **C2** | **M0** | **C1** |
| | | **C1** | | **C0** | | **C2** |
| | | **C2** | | **C3** | | **C0** |
| | | **C3** | | **C1** | | **C3** |
| | | | | | | |
| **IW3** | **M1** | **C3** | **M0** | **C1** | **M0** | **C2** |
| | | **C1** | | **C2** | | **C1** |
| | | **C0** | | **C3** | | **C0** |
| | | **C2** | | **C0** | | **C3** |
| | **M0** | **C2** | **M1** | **C0** | **M1** | **C3** |
| | | **C3** | | **C2** | | **C2** |
| | | **C1** | | **C1** | | **C0** |
| | | **C0** | | **C3** | | **C1** |

**Fig. (4): Layout of field experiment**

Where: Main plot (IW): Water regime under drip irrigation: IW1, IW2 and IW3 =100, 80 and 60 % of $ET_c$ respectively, sub-plot (M): Mulch: M0 and M1= without mulch and with mulch respectively, sub-sub-plot(C): Compost: C0, C1, C2 and C3=0, 12, 24 and 36 ton/ha respectively. Three replicates: R1, R2, and R3, number of plots=3*3*2*4=72 plots, Design: Split-split plot

**Table (4): Amount of water supply for potato growth stages under the different experimental drip water regimes during winter season in Kharga Oasis**

| Growth stage | Date | Number of days of stage | Number of irrigations | Water regime per irrigation (mm) | Water regime per stage (mm) | Water regime per stage ($m^3\ ha^{-1}$) |
|---|---|---|---|---|---|---|
| **Initial stage** | 26.10.05 - 15.11.05 | 20 | 6 | | | |
| **IW1*** | | | | 5.3 | 31.80 | 318.0 |
| **IW2** | | | | 4.25 | 25.50 | 255.0 |
| **IW3** | | | | 3.18 | 19.08 | 190.8 |
| **Development** | 16.11.05- 15.12.05 | 30 | 10 | | | |
| **IW1** | | | | 9.28 | 92.80 | 928.0 |
| **IW2** | | | | 7.4 | 74.00 | 740.0 |
| **IW3** | | | | 5.57 | 55.70 | 557.0 |
| **Mid - season** | 16.12.05 -24.01.06 | 40 | 13 | | | |
| **IW1** | | | | 13.94 | 181.20 | 1812.0 |
| **IW2** | | | | 11.15 | 144.95 | 1449.5 |
| **IW3** | | | | 8.36 | 108.68 | 1086.8 |
| **Late - season** | 25.01.06 - 14.02.06 | 20 | 6 | | | |
| **IW1** | | | | 11.27 | 67.60 | 676.0 |
| **IW2** | | | | 9 | 54.00 | 540.0 |
| **IW3** | | | | 6.76 | 40.56 | 405.6 |
| **Maturity** | 15..02.06 - 26.02.06 | 12 | 3 | | | |
| **IW1** | | | | 9.27 | 27.80 | 278.0 |
| **IW2** | | | | 7.4 | 22.20 | 222.0 |
| **IW3** | | | | 5.57 | 16.70 | 167.0 |
| **Total** | 26.10.05 - 26.02.06 | | | | | |
| **IW1** | | | | | 401.20 | 4012.0 |
| **IW2** | | | | | 320.65 | 3206.5 |
| **IW3** | | | | | 240.72 | 2407.2 |

*IW: Water regime under drip irrigation: IW1, IW2 and IW3 =100, 80 and 60 % of $ET_c$ respectively

**4.6.2.*Mulch treatments(sub-plot):-***

Mulch was prepared using sugar cane wastes by rate of 24 ton $ha^{-1}$. Two mulch treatments (with and without mulch) were applied.

**4.6.3.*Compost treatments(sub-sub-plot):-***

Table (5) illustrated some chemical properties of the applied compost. Fine compost was added during seed bed preparation at the rates of 0, 12, 24, 36 ton $ha^{-1}$.The compost was prepared using sugar cane wastes enriched with the following during composting process:

a. Ammonium sulphate (20.5 % N) at the rate of 5 kg $ton^{-1}$
b. Superphosphate (15.5 % $P_2O_5$) at the rate of 12.5 kg $ton^{-1}$
c. Potassium sulphate ( 48-52 % $K_2O$) at the rate of 12.5 kg $ton^{-1}$
d. Effective micro organisms were a mixed culture of beneficial micro-organisms including a predominant population of (Bacillus subtlis F.50, F.30), B. Theremogensid F.64), Trichoderma reesci F. 418) and yeast (Sacchromyces cerevisia FN.10).

***4.7. Fertilization:-***

Phosphorus (142.8 kg $P_2O_5$ /ha), potassium (228.6 kg $K_2O$ /ha) and 75% nitrogen (214.3 kg N /ha) fertilizers were applied in different rates according potato growth stage as recommended doses by the Ministry of Agriculture and Land Reclamation (MALR) in Egypt for the new reclaimed sandy soils.

***4.8. Water consumption for Potato at Kharga Oasis in Egypt:-***

Water consumption (Actual crop evapotranspiration) was calculated according to Israelsen and Hansen (1962) as follows:-

$$CU = D * Bd * (e_2 - e_1) * 10000 / 100$$

**Where:**

**CU:** Water consumption in $m^3$/ha.

**D:** Soil depth in m.

**Bd:** Soil bulk density (g $cm^{-3}$).

**$e_1$:** Soil moisture % immediately prior to the next irrigation directly.

**$e_2$:** Soil moisture % in 24 hours after irrigation.

**Table (5): Some chemical properties of the applied compost**

| pH | EC $dS^{-1}$ | $Na^{+}$ % | Moisture % | CEC C mol $kg^{-1}$ | Mineral content Ash % |
|---|---|---|---|---|---|
| **6.86** | 1.8 | 0.01 | 4.1 | 125 | 41.6 |
| | | | **Organic components** | | |
| **O.M %** | **O.C %** | | **O.N %** | | **C/N ratio** |
| **54.3** | 31.5 | | 1.8 | | 17.5 |
| **Macro elements %** | | | **Heavy metals ppm** | | |
| **$P_2O_5$ %** | **$K_2O$** | **$NH_4$+$NO_3$** | **Cd** | **Co** | **Ni** |
| **0.73** | 0.47 | 0.01 | 0.4 | 0.06 | 0.02 |

### *4.9. Water economy:-*

Water economy for potato was calculated as follows:-

Water economy ($kg/m^3$) =Yield in kg/ Amount of added water in $m^3$

### *4.10. Water use efficiency (WUE):-*

Water use efficiency was expressed in kg of yield/$m^3$ of used water (FAO, 1982). So, water use efficiency was calculated according to the following equation:-

Water use efficiency ($kg/m^3$) = Yield / Amount of water consumed

### *4.11. Water application efficiency:-*

Water application efficiency (WAE) was calculated using the following relation (El-Meseery, 2003): WAE = $V_s / V_a$

Where: WAE = Water application efficiency, (%)

$V_s = (\theta1 - \theta2) * d * \rho * A$

$V_s$ = Volume of stored water in root zone ($cm^3$)

$V_a$ = Volume of applied water ($cm^3$)

A = Wetted surface area of root zone ($cm^2$)

d = Soil layer depth (cm)

$\theta1$ = Soil moisture content after irrigation (%)

$\theta2$ = Soil moisture content before irrigation (%)

$\rho$ = Bulk density of soil ($g\ cm^{-3}$)

### *4.12. Fertilizer use Efficiency (FUE)*

This terminology refers to the production of crop yield / applied nitrogen, phosphorus or potassium. It was calculated according to Barber (1976) as follows:

FUE = Yield (kg/ha) /applied fertilizer (kg/ha)

Where: FUE = Fertilizer use efficiency, (kg / kg)

### *4.13. Soil sampling:-*

#### *4.13.1. Soil moisture determination*

To estimate moisture content using Gravimetric Method, soil samples were collected immediately before and 24 hours after irrigation by open Auger 0.90 m length. The samples were taken horizontally at 0.00-0.10 and 0.10-0.30 m away from the emitter and vertically at 0.00-0.20, 0.20-0.40 and 0.40-0.60 m directly under the emitter, and then these samples were transferred to laboratory and dried at 105 °C.

#### *4.13.2. Soil sampling for analyses:-*

The samples were composed before the harvest, to determine soil physical analyses, horizontally at 0.00-0.10 and 0.10-0.30 m away from the emitter and vertically at 0.00-0.20, 0.20-0.40 and 0.40-0.60 m directly under the emitter.

### *4.14. Plant sampling :-*

Three test plants were randomly selected at 80 days after planting to conclude some growth parameters of potato (plant height, number of branches per plant), after that the plant shoots were dried at 70 °C and milled to preparing them for analyses.

### *4.15. Yield and yield components:-*

The crop was harvested individually from each experimental plot 122 days after planting to record average tuber weight, average number of tubers per plant, average yield per plant, and total tuber yield (ton/ha).

### *4.16. Determination of soil properties:-*

1. Soil texture was determined using the pipette method (Klute, 1986).
2. The following determinations were carried out according to Cottenie et al. (1982):
   a. Soil reaction: soil pH was measured in a 1:1 soil- water suspension by glass electrode.
   b. Electrical conductivity (EC) of soil was measured in a 1:1 soil water extract..
   c. Calcium carbonate was determined volumetrically using Collins Calcimeter.

3. Moisture characteristics and pore size distribution:

a. Soil bulk density and total porosity: Soil bulk density and total porosity were determined according to Dewis and Freitas (1970).

b. Moisture retention: Soil moister equilibrium values over the range from 0.0 to 15 bars were carried out using the pressure membrane apparatus (Loveday, 1974). Moisture content of the soil was determined gravimetrically.

c. Pore size distribution: Pore size distribution was calculated using the data obtained from a and b (Loveday, 1974).

4. Water transmitting properties:

a. Infiltration rate (cm $h^{-1}$) was determined using the double ring method (Michael, 1978).

b. Hydraulic conductivity was determined under constant head (m $day^{-1}$) as described by Black (1965).

c. Mean diameter of soil pores ($\mu m$): Mean diameter of soil pores was estimated after Dielman and De Ridder (1972). The following equation was used for calculating the mean diameter of soil pores:

$$d = 6.177637 \sqrt{K} \quad \text{microns}$$

Where K is the hydraulic conductivity (m $day^{-1}$) corrected at $20^{o}C$ (El-Hady, 1979)

### *4.17. __Determination of N, P and K in the plant :-__*

The plant samples were milled and then digested with $H_2SO_4$ and $H_2O_2$, N, P and K analyses were confirmed according to Cottenie et al. (1982) as follows:-

1. Nitrogen: total nitrogen was determined by the modified micro-Kjeldahl method.
2. Phosphorus: phosphorus was estimated colorometerically using NH4-Meta vanidate method.
3. Potassium: potassium content was measured photometrically by flame photometer.

## *4.18.* ***Economic analysis.***

Net income was determined by the following equation:

Net profit (NP)(Net income) = Total income for output - Total costs for Inputs

Table (6) showed some details around above equation (Rizk, 2007).

### *4.18.1.Irrigation costs:*

Capital cost for different irrigation systems was calculated using current dealer prices according to 2010/2011 price level for equipment and installation (ASAE Standard, 1997).

A- Fixed costs:

The annual fixed costs of capital invested in the irrigation systems were calculated using the equation (N):

$$F.C. = D + I + T \qquad (N)$$

Where:

| | | |
|---|---|---|
| F.C. | = The annual fixed cost, | (Euro/year) |
| D | = The depreciation irrigation system, | (Euro/year) |
| I | = The interest, and | (%) |
| T | = Taxes and overheads ratio. | (Euro/year) |

Depreciation of irrigation system was calculated using the equation (N1):

$$D = [(I.C)-(Sv)] / (EL) \qquad (N1)$$

Where:

| | | |
|---|---|---|
| I.C | = The initial cost of irrigation system, | (Euro) |
| Sv | = Salvage value after depreciation and | (Euro) |
| E.L | = The expected life of the irrigation system components | (years) |

Interest on capital was calculated using the equation (N2):

I= (I.C /2)

**Table (6): Method for calculation the net profit (net income)**

| **Item** | **Water regime treatments**<br>**Mulch rates**<br>**Compost rates** | **All treatments** |
|---|---|---|
| **List of inputs** | Cost of irrigation, Euro/ha<br>Cost of mulch, Euro/ha<br>Cost of compost, Euro/ha<br>Cost of land preparation, Euro/ha<br>Cost of tuber seeds, Euro/ha<br>Cost of fertilizers NPK Euro/ha<br>Cost of weed control, Euro/ha<br>Cost of pest control, Euro/ha<br>Cost of harvesting, Euro/ha<br><br>Total costs of inputs, Euro/ha | |
| **Output** | Yield, ton/ha<br>Price, Euro<br>Total profit for output, Euro/ha | |
| **Net profit (NP)(Net income) = Total income for output - Total costs for Inputs** | | |

B- Running Costs:

The annual running cost was calculated using the equation (N3):

R.C = L + E + (R&M) (N3)

Where:

| | | |
|---|---|---|
| R.C. | = Annual running cost, | (Euro/year) |
| L | = Labor cost, | (Euro/year) |
| E | = Energy cost, and | (Euro/year) |
| (R&M) | = Repairs and maintenance costs. | (Euro/year) |

Power cost, was calculated using the equation (N4):

Bp= (Q

$$E.C = 1.2\ Bp \times H \times S \times F \qquad (N5)$$

Where:

| | | |
|---|---|---|
| E.C | = Energy cost of diesel, | (Euro/kW) |
| H | = Annual operating hours, | (h) |
| S | = Specific fuel consumption, | (l/kW/h) |
| F | = Fuel price, and | (Euro/l) |
| 1.2 | = Factor accounting for lubrication. | |

Repair and maintenance costs, was taken as 2.0 % of the initial cost.

The total cost = Fixed cost + Running cost, (Euro/ha/year) (N6)

### ***4.19. <u>Statistical analysis</u>***

The data were subjected to the proper statistical analysis of variance according to Steel and Torrie (1980) and means of treatments were compared by the least significant difference (L.S.D.) at 5% and 1% levels using COSTAT computer software package.

*5.RESULTS*

Kharga Oasis is situated in arid zone at longitude of 30° 34` eastern of Greenwich and latitude of 25° 26` northern of the equator; its climate is characterized by scarcity of rainfall, extremely low relative air humidity, hot summer and cold winter. Therefore the long-term average annual and daily air temperature amplitudes are very high. It is also characterized by strong winds, high light intensity, inconsiderable mean sky cloud cover and strong reflection from the light colored land surface (Egyptian Meteorological Authority, 1996).

The available meteorological data of the meteorological station in the area of study included air temperature (maximum, minimum and mean), relative humidity, cloud cover, rainfall, wind velocity and vapor pressure deficit, as represented in table (7), It is clear that the dominant characteristics in Kharga area is the period of high temperature with almost total lack of precipitation for at least nine months where irrigation is obviously needed. Ombrothermic diagram (fig.5) clarified the relation between monthly temperature (T°C) and monthly precipitation (P mm) with a scale of temperature is double of precipitation (T = 2P) to show the dry and humid period of the year i.e. when T > 2P = dry period and when T< P = humid period. Data clearly showed that all the months of the year are considered dry. Accordingly the vegetation in the area is seriously affected by strong heat without any natural precipitation.

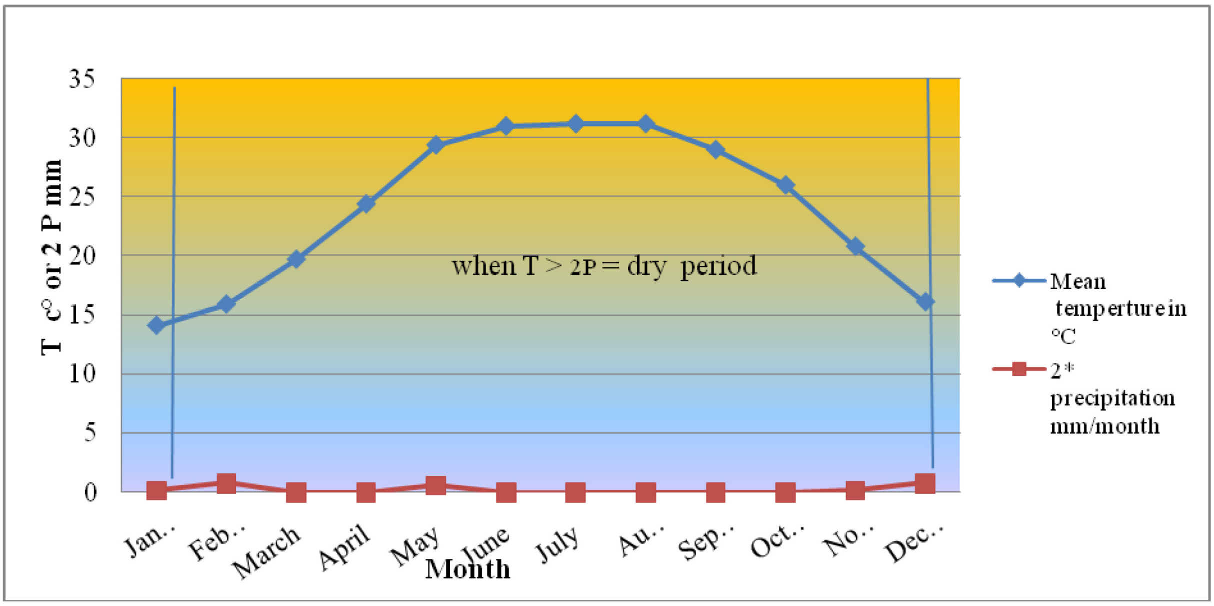


**Fig. (5): Ombrothermic diagram for Kharga Oasis**

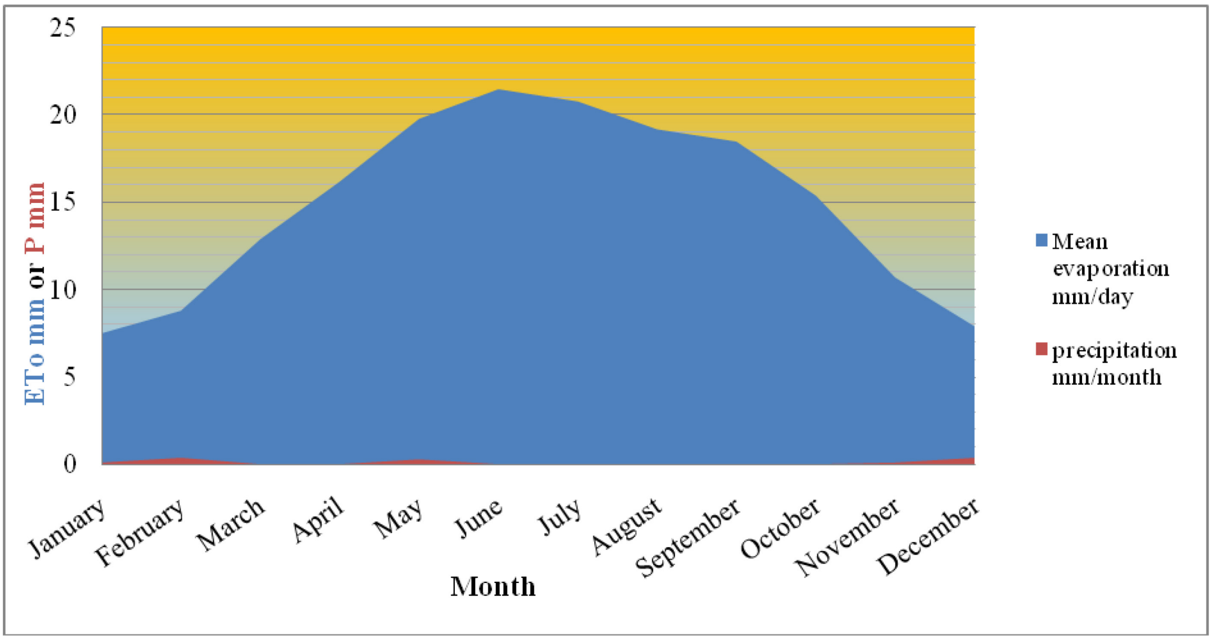


**Fig (6): Mean evaporation and mean precipitation at Kharga Oasis over the year**

Data showed that the annual precipitation in the area of study is 1.4 mm. This means that this area lies in the climatic zone (extreme arid i.e. it is not suitable for temperate crops without irrigation). Table (7) also showed that the annual potential evapotranspiration ($ET_0$) using class A pan evaporometer is 5470.7 mm. In winter season (October to February) evapotranspiration is relatively low in the range of 477.4 to 255.2 mm/ month, while in summer months $ET_0$ increases up to 645 mm/ month (21.5 mm/day). In the peak month of June, the value of $ET_0$ amounts to 11.8 % of the annual evapotranspiration while in December and January potential evapotranspiration equals only to 8.7 % of the annual $ET_0$. The peak summer $ET_0$ value is 2.77 times higher than the lowest winter value.

On the other hand, rainfall (1.4 mm/ year) collects only 0.0025 % of that of the annual $ET_0$. In other words, annual $ET_0$ is 3907.6 times more than annual precipitation. Rainfall and $ET_0$ are both plotted cumulatively. It is well known that months in which rainfall exceeds $ET_0$ are considered humid and those in which rainfall plus the water stored in the soil from the previous rain covers less than half of $ET_0$ are dry. The remainder is intermediate, accordingly, data illustrated in figures (5 and 6) clarified that the whole year is extremely dry in the area under study.

Taking into consideration that all parameters are presented as a general means for data of experiment using split-split plot design where statistically the triple interactions among treatments are the most important, obtained results are explained as follows:-

**Table (7): Meteorological Data for El-Kharga Oasis***

| Meteorological Data | Maximum temperature in °C | Minimum temperature in °C | Mean temperature in °C | Mean relative humidity % | Mean cloud cover in Octas | Mean evaporation $mm.day^{-1}$ | Monthly evaporation mm | Mean precipitation mm/month | Mean wind velocity at 2 m height in $m.s^{-1}$ | Vapour pressure deficit in mmHg | Mean daily solar radiation in $cal.day^{-1}.cm^{-2}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **January** | 22.3 | 5.9 | 14.1 | 47 | 1.2 | 7.5 | 232.5 | 0.1 | 0.75 | 5.6 | 572 |
| **February** | 24.4 | 7.4 | 15.9 | 43 | 1.0 | 8.8 | 255.2 | 0.4 | 0.92 | 7.1 | 669 |
| **March** | 28.3 | 11.1 | 19.7 | 35 | 0.9 | 12.9 | 399.9 | trace | 1.17 | 10.4 | 786 |
| **April** | 33.1 | 15.7 | 24.4 | 30 | 0.8 | 16.2 | 486 | trace | 1.33 | 15.1 | 884 |
| **May** | 37.6 | 21.2 | 29.4 | 29 | 1.0 | 19.8 | 613.8 | 0.3 | 1.42 | 21 | 940 |
| **June** | 38.6 | 23.3 | 31.0 | 29 | 0.2 | 21.5 | 645 | trace | 1.67 | 23.5 | 957 |
| **July** | 39.1 | 23.3 | 31.2 | 29 | 0.2 | 20.8 | 644.8 | 0.0 | 1.25 | 23.7 | 948 |
| **August** | 39.4 | 23.0 | 31.2 | 31 | 0.1 | 19.2 | 595.2 | 0.0 | 1.08 | 22 | 902 |
| **September** | 26.5 | 21.5 | 29.0 | 35 | 0.1 | 18.5 | 555 | 0.0 | 1.67 | 18.1 | 826 |
| **October** | 34.0 | 18.6 | 26.0 | 39 | 0.4 | 15.4 | 477.4 | trace | 1.33 | 14.4 | 716 |
| **November** | 28.6 | 13.0 | 20.8 | 43 | 0.8 | 10.7 | 321 | 0.1 | 0.92 | 9.5 | 606 |
| **December** | 23.9 | 8.3 | 16.1 | 50 | 1.3 | 7.9 | 244.9 | 0.4 | 0.84 | 6.1 | 542 |

*the meteorological station in the area of study

### 5.1. *Growth response of potato plants after 80 days of plantation as affected by applying compost, soil mulching and irrigation regimes:-*

Data presented in tables and illustrated in figures to show the effect of examined treatments and interactions on the growth response of potato plants under Kharga Oasis (Western Desert, Egypt) conditions after 80 days of plantation i.e. ≈ middle of growth season. With this respect, growth response of potato plants is expressed by plant height (m) and number of branches/plant on one side and concentration of nitrogen, phosphorus and potassium in the plants (%), on the other side.

#### 5.1.1. *Plant height(m) and number of branches/plant:-*

Plant height values changed around 0.44m (±0.074) while number of branches per plant values ranged about 4.5 (±1.18). However, the triple interaction (60 % of $ET_c$ water regime + 36 ton $ha^{-1}$compost + mulch) produced the highest value of both parameters.

##### 5.1.1.1. *General effect of individual factors :-*

Data illustrated in figure (7) showed the effect of incorporating compost at three rates (12, 24 and 36 ton $ha^{-1}$) compared to that of the soil that didn't receive compost on both parameters of growth response under study.

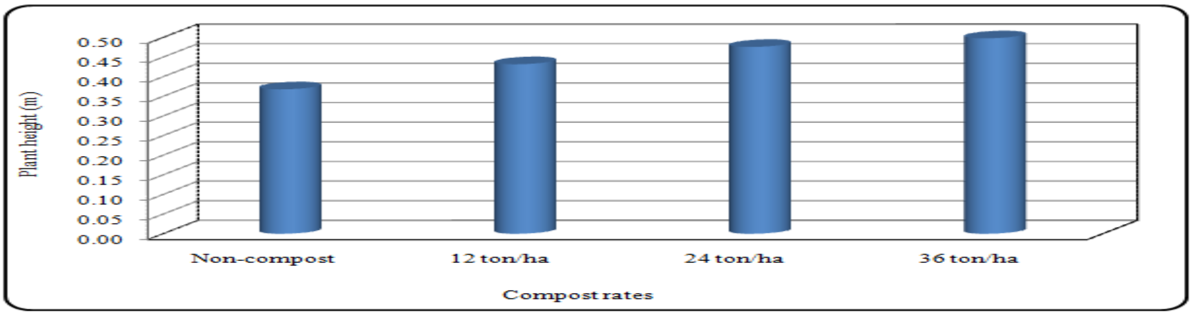


**Fig. (7): Effect of compost on plant height**

It could be noticed that there was considerable increase in either plant height or number of branches per plant under all application rates of compost. Compared to the soil that was untreated with compost, increments in plant height were 16.2, 29.7 and 35.1 % for the applied compost at 12, 24 and 36 ton $ha^{-1}$, respectively. Relevant values for number of branches per plant were 31.6, 50.4 and 64.7 %.

Regarding the effect of soil mulching on parameters of growth response i.e. plant height in meters and number of branches per plant after 80 days of plantation, it could be observed that mulching the soil with dried sugar cane wastes insignificantly increased plant height, while the number of branches per plant was significantly increased.

On the other hand, the effect of applying three water regimes **(**fig.8**)**, data in hand detected that either plant height or number of branches per plant gradually decreased with increasing the amounts of irrigation water from 60 % of the $ET_c$ to 100% of the $ET_c$, as applying the amounts of irrigation water equals to the 100 % of the $ET_c$ gave the shortest plants accompanied with the lowest number of branches/plant. In other words, the decreases in plant height by increasing applied water amounted to 93.8 and 79.6 % using 80 and 100% of the $ET_{crop}$ compared to that of using 60 % of the $ET_{crop}$. The same is true for number of branches/plant; it was calculated as 92.3 and 72.1 % that of the irrigated soil with 60 % of the $ET_{crop}$, respectively.

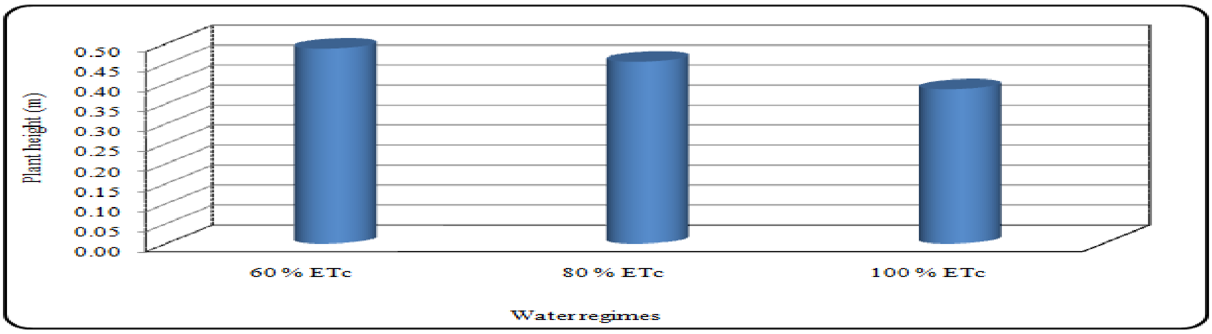


**Fig. (8): Effect of water regime on plant height.**

***5.1.1.2. <u>Effect of interactions among the studied factors on plant height and number of branches/plant:</u>***

Tables (8 to 11) showed the influence of the double and triple interactions between water regimes, mulch and compost on mean plant height and mean number of branches per plant. Data in hand refer to the following:-

As for data in a table (8), there were considerable effects of the interaction between water regime and mulch on mean plant height and mean number of branches per plant. In detail, decreasing water regimes combined with mulch increased mean plant height and mean number of branches per plant. The highest plants and number of branches were achieved under 60 % of $ET_c$ of water regime in mulched soil. While the shortest plants and the lowest number of branches were obtained under 100 % of $ET_c$ of water regime in the same mulched soil.

The obtained data represented in table (9) affirmed that actually there was significance for the interaction between water regime and compost on plant height and number of branches per plant. Thoroughly, decreasing irrigation water levels combined with increasing applying compost rates led to increase plant height and number of branches except that in the combination between 100 % of $ET_c$ of applied water and 36 ton $ha^{-1}$of compost. The highest plants and their number of branches were recorded by 36 ton $ha^{-1}$compost rate under 60 % of $ET_c$ of water regime while the shortest plants and lowest number of branches were attained without compost under 100 % of $ET_c$ of water regime.

**Table (8): Effect of the interaction between water regimes and soil mulching on plant height and number of branches per plant**

| Water regime | Mulch | Plant height (m) | Number of branches/plant |
|---|---|---|---|
| **100 % of $ET_c$*** | **Non-mulch** | 0.41 | 4.055 |
| | **Mulch** | 0.37 | 3.31 |
| **80 % of $ET_c$** | **Non-mulch** | 0.45 | 4.48 |
| | **Mulch** | 0.47 | 4.94 |
| **60 % of $ET_c$** | **Non-mulch** | 0.48 | 4.79 |
| | **Mulch** | 0.50 | 5.42 |
| **LSD at 5%** | | **0.018** | **0.259** |
| **LSD at 1%** | | **0.027** | **0.392** |

* = 4000 $m^3$/ha

Concerning the effect of the double interaction between compost and mulch on plant height and number of branches/plant, data in table (10) explained that increasing applied compost rate from 0 to 12 ton $ha^{-1}$with soil covering significantly increased mean plant height and mean number of branches per plant compared to those when applying compost at the same rates without soil covering but then more increase of applying compost rates with soil covering significantly decreased mean plant height and mean number of branches per plant. In addition, the differences were insignificant between compost rates at 24 and 36 ton $ha^{-1}$under soil covering.

The highest values were attained using (36 ton $ha^{-1}$of compost+ soil covering). While, the lowest values were recorded by the double interaction (none compost + none mulch).

**Table (9): Effect of the interaction between water regimes and compost on plant height and number of branches per plant**

| Water regime | Compost | Plant height (m) | Number of branches |
|---|---|---|---|
| **100 % of $ET_c$*** | **Non-compost** | 0.35 | 3.10 |
| | **12 ton/ha** | 0.39 | 3.66 |
| | **24 ton/ha** | 0.42 | 4.05 |
| | **36 ton/ha** | 0.39 | 3.92 |
| **80 % of $ET_c$** | **Non-compost** | 0.39 | 3.65 |
| | **12 ton/ha** | 0.43 | 4.37 |
| | **24 ton/ha** | 0.48 | 5.12 |
| | **36 ton/ha** | 0.53 | 5.72 |
| **60 % of $ET_c$** | **Non-compost** | 0.37 | 3.13 |
| | **12 ton/ha** | 0.48 | 4.97 |
| | **24 ton/ha** | 0.52 | 5.68 |
| | **36 ton/ha** | 0.58 | 6.63 |
| **LSD at 5%** | | **0.015** | **0.283** |
| **LSD at 1%** | | **0.020** | **0.379** |

* = 4000 m³/ha

**Table (10): Effect of the interaction between soil mulching and compost on plant height and number of branches per plant**

| Mulch | Compost | Plant height (m) | Number of branches |
|---|---|---|---|
| **Non-mulch** | **Non-compost** | 0.37 | 3.10 |
| | **12 ton/ha** | 0.42 | 4.16 |
| | **24 ton/ha** | 0.47 | 4.82 |
| | **36 ton/ha** | 0.51 | 5.69 |
| **Mulch** | **Non-compost** | 0.37 | 3.49 |
| | **12 ton/ha** | 0.44 | 4.50 |
| | **24 ton/ha** | 0.48 | 5.08 |
| | **36 ton/ha** | 0.49 | 5.16 |
| **LSD at 5%** | | **0.012** | **0.231** |
| **LSD at 1%** | | **0.016** | **0.310** |

Obtained results in table (11) indicated that the triple interaction among water regimes, mulch and compost rates resulted in significant difference on mean plant height and mean number of branches per plant. In other words, the decrement of applied water with increasing applied compost rates increased mean plant height and mean number of branches per plant in mulched and non-mulched soil, except under 100 % of $ET_c$ where soil mulching reduce mean plant height and mean number of branches per plant with all incorporating compost rates in the mulched soil compared to non mulched one. Therefore the highest plants and their number of branches were obtained by the combination between 60 % of $ET_c$ water regime, soil mulching and applying 36 ton $ha^{-1}$of compost. While the shortest plants and the lowest number of branches/plant were recorded either without applying compost or with compost rate at 36 ton $ha^{-1}$under 100 % of $ET_c$ of water regime in mulched soil (Fig. 9).

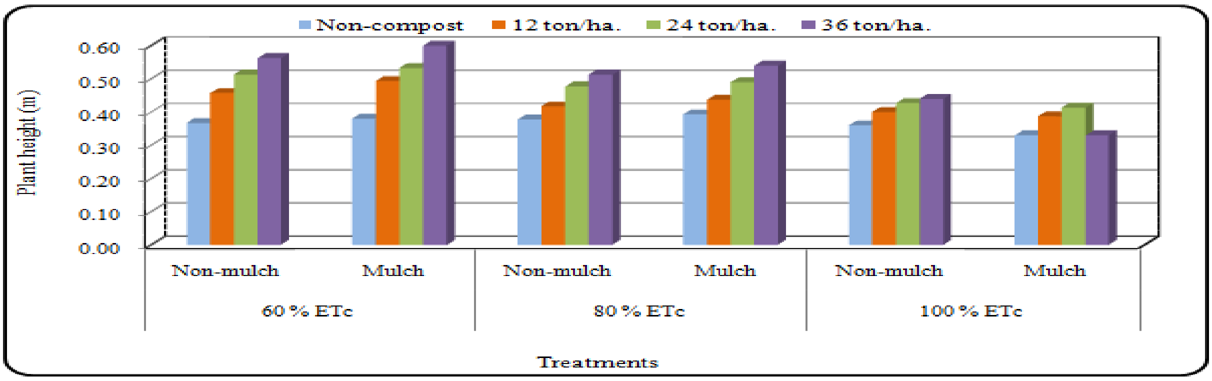


**Fig. (9): Effect of the interaction among water regimes, mulch and compost on plant height**

**Table (11): Effect of the interaction among water regimes, mulch and compost on plant height and number of branches per plant**

| Property | Water regime | Mulch | Compost (ton $ha^{-1}$) | | | |
|---|---|---|---|---|---|---|
| | | | Non-compost | 12 | 24 | 36 |
| Plant height (m) | 100 % of $ET_{c*}$ | Non-mulch | 0.36 | 0.40 | 0.43 | 0.44 |
| | | Mulch | 0.33 | 0.39 | 0.41 | 0.33 |
| | 80 % of $ET_c$ | Non-mulch | 0.38 | 0.42 | 0.48 | 0.51 |
| | | Mulch | 0.39 | 0.44 | 0.49 | 0.54 |
| | 60 % of $ET_c$ | Non-mulch | 0.37 | 0.46 | 0.51 | 0.56 |
| | | Mulch | 0.38 | 0.49 | 0.53 | 0.60 |
| | LSD at 5% | | 0.021 | | | |
| | LSD at 1% | | 0.029 | | | |
| Number of branches per plant | 100 % of $ET_c$ | Non-mulch | 3.10 | 3.79 | 4.30 | 5.03 |
| | | Mulch | 3.10 | 3.53 | 3.80 | 2.80 |
| | 80 % of $ET_c$ | Non-mulch | 3.37 | 3.90 | 5.07 | 5.60 |
| | | Mulch | 3.93 | 4.83 | 5.17 | 5.83 |
| | 60 % of $ET_c$ | Non-mulch | 2.83 | 4.80 | 5.10 | 6.43 |
| | | Mulch | 3.43 | 5.13 | 6.27 | 6.83 |
| | LSD at 5% | | 0.401 | | | |
| | LSD at 1% | | 0.536 | | | |

* = 4000 $m^3$/ha

### *5.1.2. Nitrogen, phosphorus and potassium concentration in the plants:-*

Plant nutrient percentages as influenced by applying compost, soil mulching and water regimes are given in tables (12-17) for nitrogen, phosphorus and potassium. Figures (10-18) illustrated the effect of the aforementioned factors on the studied plant nutrients.

#### *5.1.2.1. Nitrogen:-*

Data in hand pointed to that nitrogen percentage in the potato plant generally varied around 2.8 (±0.714). On the other hand, the triple interaction between (60 % of $ET_c$ water regime + 36 ton $ha^{-1}$compost + mulch) obtained the maximum value (3.98 %).

##### *5.1.2.1.1. General effect of individual* **factors on nitrogen:-**

Percentages of nitrogen in potato plants were significantly affected by applying compost (fig.10). The more the amount of applied compost was, the higher was nitrogen concentration in the plant. In detail, increments in nitrogen concentration in potato plants treated with compost, compared to that of the plants which didn't receive compost were 34.4, 63.6 and 77.4 % for the applications 12, 24 and 36 ton $ha^{-1}$of compost, respectively.

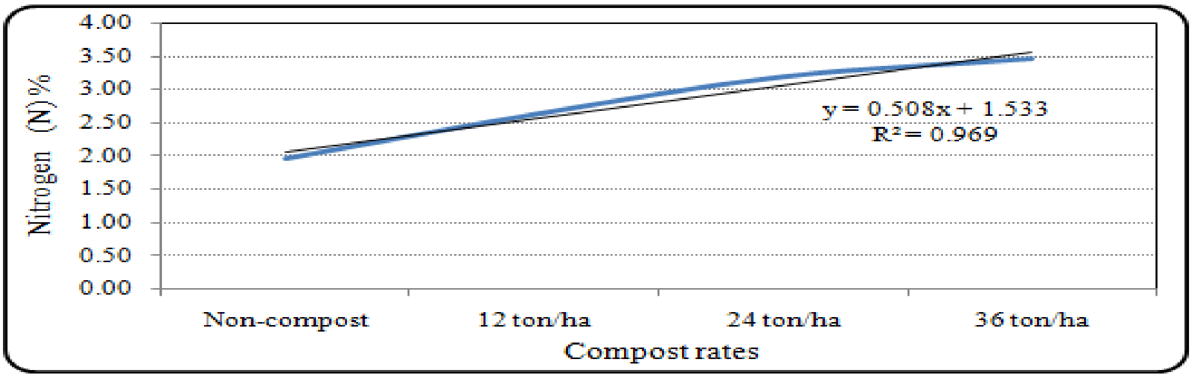


**Fig. (10): Effect of compost on nitrogen concentration in potato plant**

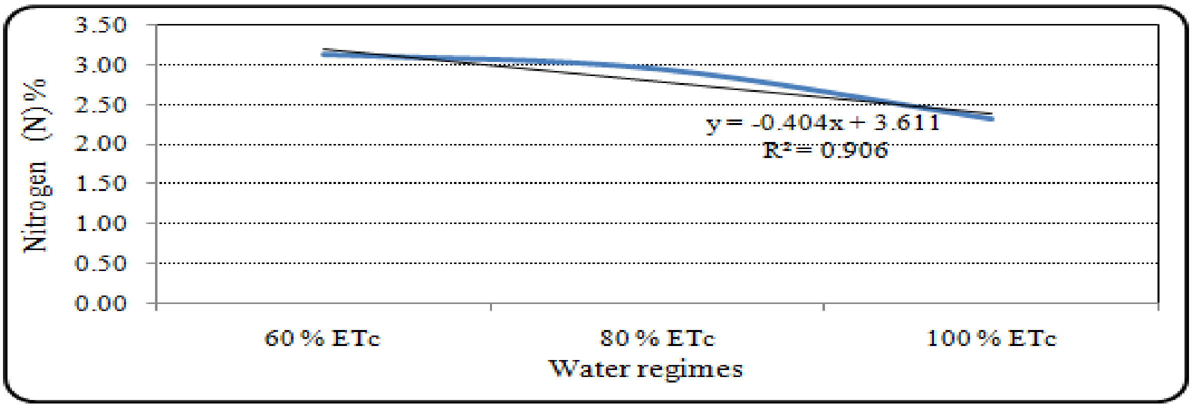


**Fig.(11): Effect of water regime on nitrogen concentration in potato plant**

Data revealed that it could be noticed that soil mulching generally increased the values of nitrogen percentage in potato plant. Comparing the nitrogen percentage of the potato plants in the mulched soil to that of the plants in the non-mulched one, nitrogen percentage of the former was higher than that of the latter by 2.17 %. But increasing irrigation water led to significant decrease in nitrogen percentage in the plant (fig.11).

### ***5.1.2.1.2. Effect of interactions among the studied factors on nitrogen:-***

Tables (12- 17) showed the effect of the double and triple interactions between water regimes, mulch and compost on nitrogen (N) concentration in the potato plant.

Concerning the interaction between water regime and mulch shown in table (12), it's clear that there were different influences on nitrogen percentage. In detail, comparing without soil mulching, the increment in irrigation water levels with soil mulching significantly decreased nitrogen percentage for the interaction (100 % of $ET_c$ of water regime + soil mulching), other than significantly increased nitrogen percentage for the interaction (80 % of $ET_c$ of water regime + soil mulching) and insignificantly for the interaction (60 % of $ET_c$ of water regime + soil mulching).

**Table (12): Effect of the interaction between water regime and mulch on nutrient concentration (%) in potato plant**

| Water regime | Mulch | Nitrogen (N) | Phosphorus (P) | Potassium (K) |
|---|---|---|---|---|
| **100 % of $ET_c$*** | **Non-mulch** | 2.43 | 0.25 | 5.91 |
| | **Mulch** | 2.22 | 0.25 | 5.68 |
| **80 % of $ET_c$** | **Non-mulch** | 2.82 | 0.28 | 6.30 |
| | **Mulch** | 3.09 | 0.29 | 6.40 |
| **60 % of $ET_c$** | **Non-mulch** | 3.07 | 0.30 | 6.70 |
| | **Mulch** | 3.19 | 0.31 | 6.87 |
| **LSD at 5%** | | **0.077** | **0.018** | **0.109** |
| **LSD at 1%** | | **0.117** | **0.027** | **0.166** |

* = 4000 $m^3$/ ha

The highest value of nitrogen percentage was determined in the plant tissue from (60 % of $ET_c$ of water regime + soil mulching) interaction. On the contrary, the greatest decrement in nitrogen percentage was found by the combination of (100 % of $ET_c$ of water regime + soil mulching).

With respect to the interaction between water regime and compost, the results presented in table (13) announced that obviously there was significance on nitrogen percentage in the potato plant. Thoroughly, decreasing irrigation water levels combined with increasing applying compost rates led to increase of nitrogen percentage in the plant. The highest value of nitrogen percentage in the plant was achieved by the combination of (60 % of $ET_c$ of water regime + 36 ton $ha^{-1}$compost rate) while the combination of (without compost + 100 % of $ET_c$ of water regime) gave the lowest nitrogen percentage in the plant.

**Table (13): Effect of the interaction between water regime and compost on nutrient concentration (%) in potato plant**

| Water regime | Compost (ton $ha^{-1}$) | Nitrogen (N) | Phosphorus (P) | Potassium (K) |
|---|---|---|---|---|
| 100% of $ET_c$* | Non-compost | 1.85 | 0.19 | 4.67 |
| | 12 | 2.17 | 0.22 | 5.38 |
| | 24 | 2.50 | 0.26 | 6.38 |
| | 36 | 2.78 | 0.31 | 6.74 |
| 80 % of $ET_c$ | Non-compost | 2.06 | 0.20 | 5.03 |
| | 12 | 2.77 | 0.27 | 6.21 |
| | 24 | 3.33 | 0.32 | 6.73 |
| | 36 | 3.65 | 0.36 | 7.44 |
| 60 % of $ET_c$ | Non-compost | 1.95 | 0.18 | 5.23 |
| | 12 | 2.91 | 0.29 | 6.60 |
| | 24 | 3.72 | 0.34 | 7.39 |
| | 36 | 3.94 | 0.40 | 7.94 |
| **LSD at 5%** | | **0.083** | **0.025** | **0.138** |
| **LSD at 1%** | | **0.110** | **0.034** | **0.185** |

* = 4000 $m^3$/ha

As regards the effect of the double interaction between compost and mulch on nitrogen percentage, data in table (14) showed that increasing applied compost rates with soil covering notably increased nitrogen concentration in the potato plant compared to without applying compost treatment. It could be noted that there was a slight increase for applying compost rate of 36 ton $ha^{-1}$ in mulched or none mulched soil, while slight decrease with no applying compost.

The highest percentage of nitrogen in the potato plant was attained from compost rate at 36 ton ha$^{-1}$in mulched soil. However, the lowest one was obtained from the interaction between (without compost + soil covering).

**Table (14): Effect of the interaction between soil mulching and compost on nutrient concentration (%) in potato plant**

| Mulch | Compost (ton ha$^{-1}$) | Nitrogen (N) | Phosphorus (P) | Potassium (K) |
|---|---|---|---|---|
| Non-mulch | Non-compost | 1.96 | 0.19 | 5.00 |
| | 12 | 2.56 | 0.26 | 6.06 |
| | 24 | 3.13 | 0.30 | 6.80 |
| | 36 | 3.44 | 0.35 | 7.36 |
| Mulch | Non-compost | 1.95 | 0.19 | 4.95 |
| | 12 | 2.68 | 0.26 | 6.07 |
| | 24 | 3.24 | 0.31 | 6.86 |
| | 36 | 3.47 | 0.36 | 7.38 |
| LSD at 5% | | 0.067 | 0.021 | 0.113 |
| LSD at 1% | | 0.090 | 0.028 | 0.151 |

As for data in table (15), there were significant influences for the triple interaction among water regimes, mulch and compost rates on nitrogen percentage in the plant. In other words, the decrement of applied water with increasing applied compost rates increased nitrogen percentage in mulched soil compared to non-mulched one(fig.12).

Highly negative effect on nitrogen percentage was observed in the interaction among (without compost + 100 % of $ET_c$ water irrigation level + mulched soil) where the lowest nitrogen percentage was obtained. On the other hand, the highest nitrogen percentage was achieved by the combination of (60 % of $ET_c$ water regime + soil mulching + applying compost at 36 ton ha$^{-1}$).

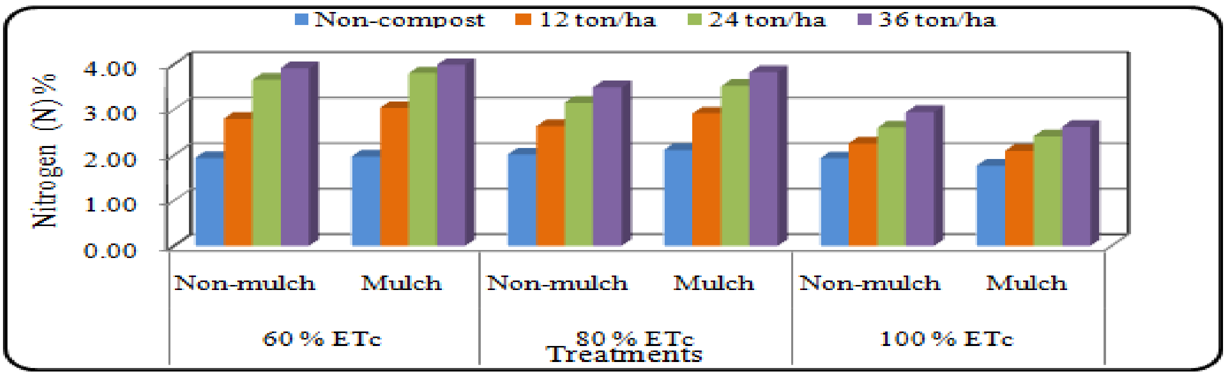


**Fig. (12): Effect of interaction among water regimes, mulch and compost on nitrogen concentration in potato plant**

**Table (15): Effect of the interaction among water regimes, mulch and compost on nitrogen concentration**

| Property | Water regime | Mulch | Compost (ton $ha^{-1}$) | | | |
|---|---|---|---|---|---|---|
| | | | Non-compost | 12 | 24 | 36 |
| Nitrogen (N) % | 100 % of $ET_c$* | Non-mulch | 1.93 | 2.25 | 2.60 | 2.94 |
| | | Mulch | 1.76 | 2.09 | 2.40 | 2.62 |
| | 80 % of $ET_c$ | Non-mulch | 2.01 | 2.63 | 3.14 | 3.48 |
| | | Mulch | 2.11 | 2.91 | 3.52 | 3.82 |
| | 60 % of $ET_c$ | Non-mulch | 1.93 | 2.79 | 3.65 | 3.90 |
| | | Mulch | 1.97 | 3.03 | 3.80 | 3.98 |
| | LSD at 5% | | 0.117 | | | |
| | LSD at 1% | | 0.156 | | | |

* = 4000 $m^3$/ha

### *5.1.2.2. <u>Phosphorus:-</u>*

Obtained data indicated that generally values of phosphorus percentage in potato plant ranged about 0.278(±0.07). However, the triple interaction between (60 % of $ET_c$ water regime + 36 ton $ha^{-1}$compost + mulch) obtained the highest value (0.40 %).

#### *5.1.2.2.1. <u>General effect of individual factors :-</u>*

It is clear that the mean values of phosphorus percentage were significantly increased by increasing compost rates over none compost treatment. In other words, the values of phosphorus percentage were 0.19, 0.26, 0.31 and 0.36 for the application rates of compost 0, 12, 24 and 36 ton $ha^{-1}$, respectively. The highest value of phosphorus percentage was obtained using a compost rate of 36 ton $ha^{-1}$ **(**fig. 13**)**.

Relating to the effect of mulching on phosphorus percentage in potato plant, it could be observed that, in general, mulching slightly increased the values of phosphorus percentage under all treatments of applying compost and water regimes. Comparing the phosphorus percentage in the plants in the mulched soil to that in the non-mulched one, the phosphorus percentage of the former was higher than that of the latter by only 3.7 %.

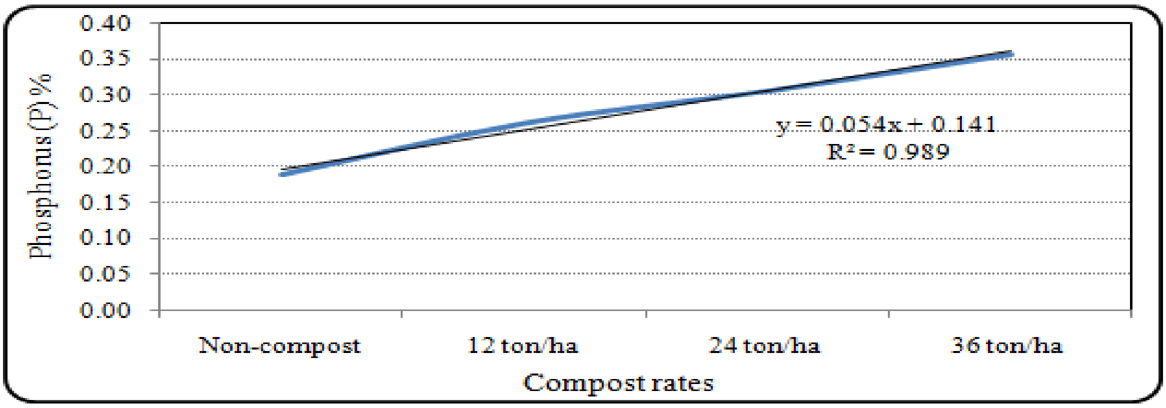


**Fig. (13): Effect of compost on phosphorus concentration in potato plant**

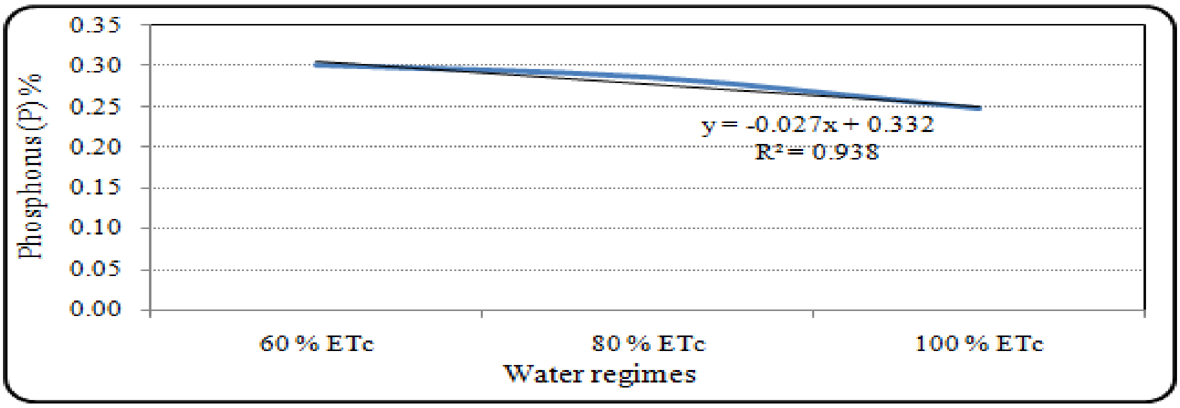


**Fig.( 14 ): Effect of water regime on phosphorus concentration in potato plant**

Data shown in figure (14) explained the effect of applying three water regimes to the soil i.e. 100, 80 and 60 % of $ET_{crop}$ on phosphorus percentage in the potato plants. Data in hand reveals that increasing applied water irrigation level from 60 to 80 % of $ET_c$ insignificantly decreased phosphorus percentage but phosphorus percentage was significantly decreased by 100 % of $ET_c$.

### *5.1.2.2.2. <u>Effect of interactions among the studied factors on phosphorus :-</u>*

Tables (12-14) and table (16) illustrated the effect of the double and triple interactions between water regimes, mulch and compost on phosphorus percentage in the potato plant.

Obtained data explained as follows:-

Regarding the interaction between water regime and mulch as shown in table (12), it could be noticed that there were different influences on phosphorus percentage. Decrement in irrigation water levels with mulch didn't have effect on phosphorus percentage for (100 % of $ET_c$ of water regime + soil mulching) compared to (100 % of $ET_c$ of water regime + without soil mulching), but phosphorus percentage was insignificantly increased for the interaction (80 % of $ET_c$ of water regime + soil mulching) and the interaction (60 % of $ET_c$ of water regime + soil mulching).

The maximum value of phosphorus percentage was determined in the plant tissue from the interaction between (60 % of $ET_c$ of water regime + soil mulching). On the contrary, the greatest decrement in phosphorus percentage was found by the interaction between (100 % of $ET_c$ of water regime + soil mulching).

About the interaction between water regime and compost, the represented results in table (13) declared that there was obviously significance for this interaction on phosphorus percentage in the potato plant. Thoroughly, decreasing irrigation water levels combined with increasing applying compost rates led to significant increase in phosphorus percentage in the plant.

The maximum value of phosphorus percentage in the plant was obtained from the combination of (60 % of $ET_c$ of water regime + 36 ton $ha^{-1}$compost). In contrast, the minimum phosphorus percentage in the plant was recorded by the combination of (60 % of $ET_c$ of water regime + without compost).

Concerning the effect of double interaction between compost and mulch on phosphorus percentage in the plant, the combined data as presented in table (14) explain that increasing applied compost rates with soil covering notably resulted in an increase in phosphorus percentage in the potato plant compared to the treatment without applying compost. It could be observed that there was a slight increase for applying 24 ton $ha^{-1}$ of compost between none mulched and mulched soil also for applying compost rate of 36 ton $ha^{-1}$. While no effect was noticed on phosphorus percentage for not applying compost between none mulched and mulched soil.

The maximum percentage of phosphorus in the potato plant was achieved by adding 36 ton $ha^{-1}$of compost in mulched soil. However, the minimum percentage of phosphorus was obtained without compost in both of none mulched and mulched soils.

From the above data in table (16) and fig.(15), there were considerable variations for the triple interaction among water regimes, mulch and compost rates on phosphorus percentage in the plant. In other words, the decrement of applied water with increasing applying compost rates at 24 and 36 ton ha$^{-1}$ increased phosphorus percentage in mulched soil compared to none mulched one.

**Table (16): Effect of the interaction among water regimes, mulch and compost on phosphorus concentration**

| Property | Water regime | Mulch | Compost (ton ha$^{-1}$) | | | |
|---|---|---|---|---|---|---|
| | | | Non-compost | 12 | 24 | 36 |
| Phosphorus (P) % | 100 % of $ET_c$* | Non-mulch | 0.19 | 0.23 | 0.26 | 0.30 |
| | | Mulch | 0.19 | 0.21 | 0.27 | 0.32 |
| | 80 % of $ET_c$ | Non-mulch | 0.20 | 0.25 | 0.31 | 0.36 |
| | | Mulch | 0.20 | 0.28 | 0.32 | 0.36 |
| | 60 % of $ET_c$ | Non-mulch | 0.17 | 0.29 | 0.33 | 0.39 |
| | | Mulch | 0.18 | 0.29 | 0.34 | 0.40 |
| | LSD at 5% | | 0.036 | | | |
| | LSD at 1% | | 0.048 | | | |

* = 4000 $m^3$/ha

Highly negative effect for phosphorus percentage was obtained for the interaction among (without compost + 60 % of $ET_c$ irrigation water level + none mulched soil) where it gave the minimum phosphorus percentage. Conversely, the maximum phosphorus percentage was achieved by the combination of (60 % of $ET_c$ water regime + soil mulching + applying compost at 36 ton ha$^{-1}$).

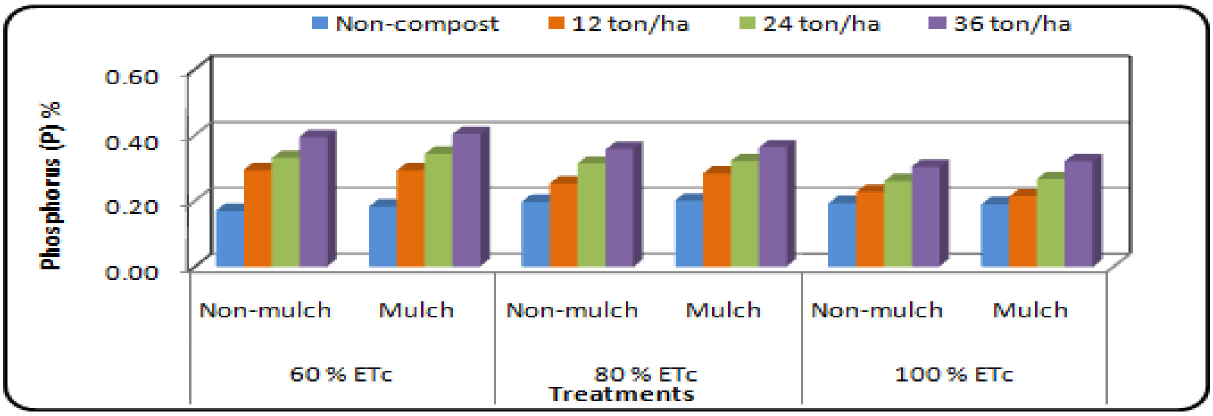


**Fig. (15): Effect of the interaction among water regimes, mulch and compost on the phosphorus concentration in potato plant**

### *5.1.2.3. Potassium:-*

Data in hand pointed out that generally values of potassium percentage in the potato plant ranged about 6.31(±1.013). However, the triple interaction between (60 % of $ET_c$ water regime + 36 ton $ha^{-1}$compost + mulch) obtained the highest value (8.02).

#### *5.1.2.3.1. General effect of the individual factors on potassium :-*

Data illustrated in figure (16) explained the effect of incorporating compost at three rates (12, 24, 36 ton $ha^{-1}$) compared to that of soil didn't receive compost on potassium percentage in the potato plant. It could be observed that there was a notable effect in all treatments on potassium percentage in the potato plant. In detail, increasing rate of compost significantly led to increase in potassium percentage in the potato plant by 21.93 %, 37.42 % and 48.30 % for the rates 12, 24 and 36 ton $ha^{-1}$, respectively.

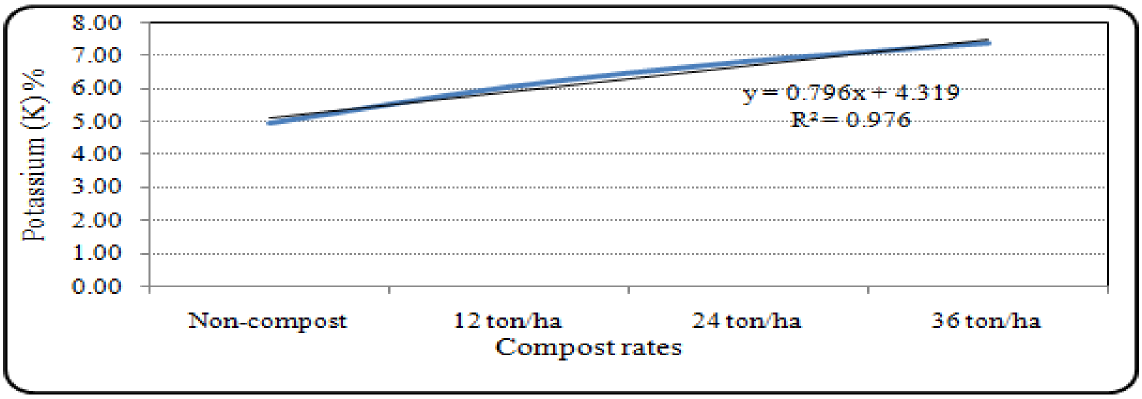


**Fig. (16): Effect of compost on potassium concentration in potato plant**

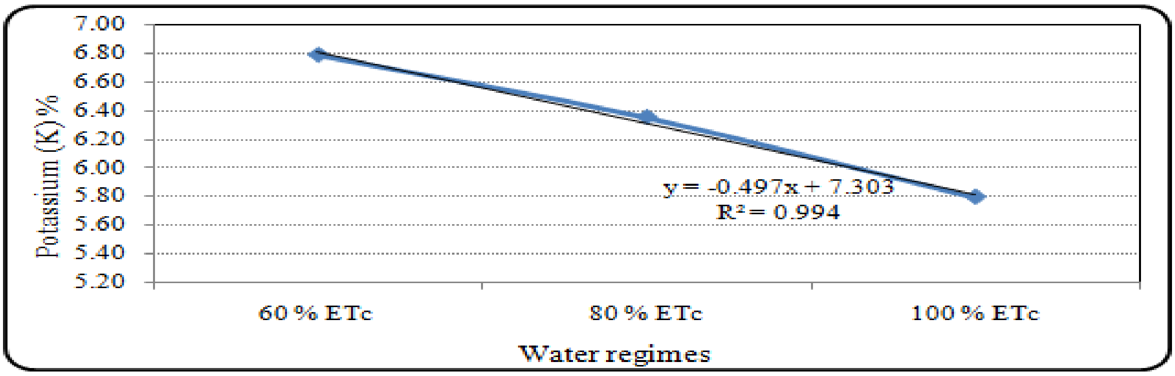


**Fig.(17): Effect of water regime on potassium concentration in potato plant**

Relating to effect of soil mulching, it can be detected that mulching the soil with dried sugar cane wastes had an insignificant influence on potassium percentage in the potato plant; comparing potassium percentage in the potato plant in the mulched soil to that in the non-mulched one, potassium percentage of the former increased by 99.68 % rather than that of the latter.

Data shown in figure (17) explained the effect of applying three water regimes to the soil i.e. 100 %, 80 % and 60 % of $ET_{crop}$. Increasing applied water significantly led to decrease in potassium percentage in potato plant. In detail, values of potassium percentage in potato plant were 5.79, 6.35 and 6.79 for irrigation regimes 100, 80, 60 % of their $ET_c$, in sequence.

### ***5.1.2.3.2. <u>Effect of interactions among the studied factors on potassium:-</u>***

Tables (12-14) and table (17) showed the effect of the double and triple interactions between water regimes, mulch and compost on potassium (K) percentage in the potato plant. Revealed data are shown the following:

Concerning the interaction between water regime and mulch, table (12) indicated that there were different influences on potassium percentage**.** In detail, comparing the treatment without soil mulching, the irrigation water level by 100% of $ET_c$ of water regime with mulch resulted in a decrease in potassium percentage significantly for (100 % of $ET_c$ of water regime + soil mulching) interaction, other than insignificantly increased potassium percentage for the interaction (80 % of $ET_c$ of water regime + soil mulching), and significantly for the interaction between (60 % of $ET_c$ of water regime + soil mulching). The maximum value of potassium percentage was determined in the plant tissue from (60 % of $ET_c$ of water regime + soil mulching) interaction. While the greatest decrement in potassium percentage was recorded by (100 % of $ET_c$ of water regime + soil mulching).

With regard to the interaction between water regime and compost, as represented results in table (13), it’s clear that there were significant differences in this interaction in potassium concentration in the potato plant. In detail, the decreasing irrigation water levels combined with increasing applying compost rates led to escalating increase of potassium concentration in the plant. The maximum concentration of potassium in the plant was attained by combination between (60 % of $ET_c$ of water regime + 36 ton $ha^{-1}$compost rate). On the contrary, the interaction, between without compost and 100 % of $ET_c$ of water regime, obtained the minimum potassium concentration in the plant.

Concerning the effect of the double interactions between compost and mulch, the combined data in table (14) showed that increasing applied compost rates with soil covering caused significant increment in potassium concentration in the potato plants compared to that didn't receive compost. It could be noticed that there was slight increase in potassium concentration by applying compost rates between none mulched and mulched soil. While insignificant decrease was noticed between none mulched and mulched soil that didn't receive compost. The maximum concentration of potassium in the potato plants was attained from compost rates at 36 ton $ha^{-1}$in mulched soil, while the minimum concentration of potassium was obtained without compost in the same soil (with soil covering).

As for data in table (17) and fig.(18), there were significant effects of the triple interactions among water regimes, mulch and compost rates on potassium percentage in the plant. In other words, the decrement of applied water with increasing applied compost rates increased potassium percentage in mulched soil compared to non-mulched one. There was a great negative effect on potassium percentage by the interaction among (without compost + 100 % of $ET_c$ water irrigation level + mulched soil), where this interaction gave the minimum potassium percentage. On the other hand, the maximum potassium percentage was achieved by the combination of (60 % its water regime + soil mulching + applying compost rate of 36 ton $ha^{-1}$).

**Table (17): Effect of the interaction among water regimes, mulch and compost on potassium concentration**

| Property | Water regime | Mulch | Compost (ton $ha^{-1}$) | | | |
|---|---|---|---|---|---|---|
| | | | Non-compost | 12 | 24 | 36 |
| Potassium (K) % | 100 % of $ET_c$ | Non-mulch | 4.78 | 5.60 | 6.39 | 6.86 |
| | | Mulch | 4.56 | 5.16 | 6.37 | 6.62 |
| | 80 % of $ET_c$ | Non-mulch | 5.01 | 6.12 | 6.72 | 7.36 |
| | | Mulch | 5.05 | 6.30 | 6.73 | 7.51 |
| | 60 % of $ET_c$ | Non-mulch | 5.21 | 6.46 | 7.28 | 7.85 |
| | | Mulch | 5.24 | 6.74 | 7.49 | 8.02 |
| | **LSD at 5%** | | **0.195** | | | |
| | **LSD at 1%** | | **0.261** | | | |

* = 4000 $m^3$/ha

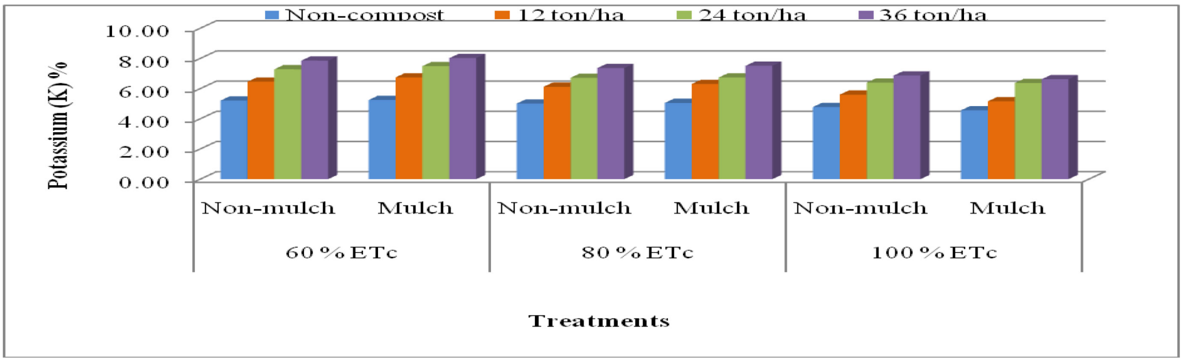


**Fig.(18): Effect of the interaction among water regimes, mulch and compost on potassium concentration in potato plant**

### *5.1.3. <u>Effect on yield components of potato:-</u>*

Data of potato yield components as affected by applying compost and mulch under drip irrigation regimes are shown as follows:-

#### *5.1.3.1. <u>Average number of potato tubers per plant:-</u>*

Number of tubers per plant values range was 3.054(±0.343). However, the triple interaction for (80 % of $ET_c$ water regime + 36 ton $ha^{-1}$compost + non mulch) produced the highest value (3.25). While the triple interactions for (60 % of $ET_c$ water regime + 0 ton $ha^{-1}$compost + non mulch) produced the lowest value (2.68).

#### *5.1.3.1.1. <u>General effect of the individual factors:-</u>*

Data illustrated in figure (19) showed the compost effect on number of potato tubers per plant. It could be noticed that there was an obvious effect in all treatments. In detail, average number of potato tubers per plant was significantly increased by 10.14, 15.22 and 17.75 % for applying 12, 24 and 36 ton $ha^{-1}$of compost compared to none compost, respectively.

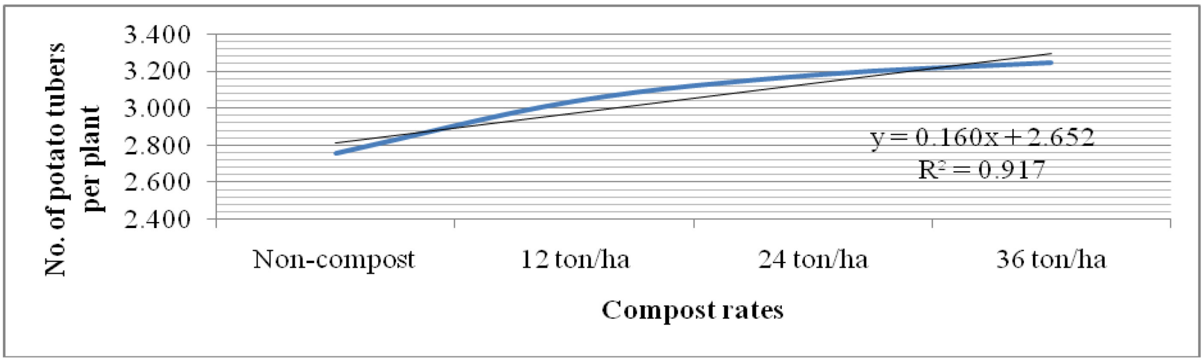


**Fig.(19): Effect of compost rates on average number of tubers per plant**

However, soil mulching generally reduced the average number of potato tubers per plant. Comparing the number of tubers per plant in the mulched soil to that of the non-mulched one, average number of potato tubers per plant of the former was lower than those of the latter by 4.16 %.

In addition, increasing applied water irrigation level from 60 to 80% of $ET_c$ increased average number of potato tubers per plant. However, increasing water level by 100 % of $ET_c$ decreased it. In detail, the percentage decrease in average number of potato tubers per plant were 13.8 and 11.0 % that of the plants irrigated by 60 % of its $ET_c$ for the plants that irrigated by 80 % and 100 % of their $ET_c$, in sequence.

***5.1.3.1.2. <u>Effect of interactions among the studied factors on average number of potato tubers per plant:-</u>***

Tables (18-21) showed the influence of the double and triple interactions between water regimes, mulch and compost on number of potato tubers per plant. Data in hand revealed the following:-

As for the data in table (18), there were considerable effects of the interaction between water regime and mulch on number of potato tubers per plant. In detail, increasing water regimes from 60 to 80 % of the $ET_c$ with mulch increased average number of potato tubers per plant but decreased by applying 100 % of the $ET_c$. The lowest number of potato tubers per plant was obtained under 60 % of the $ET_c$ water regime in mulched soil. While the highest number of potato tubers per plant was achieved by applying 80 % of the $ET_c$ water regime in non-mulched soil.

Regarding the interaction between water regime and compost, the increment in irrigation water levels from 60 to 80 % of the $ET_c$ combined with increasing applied compost led to increase in the average number of potato tubers per plant, but decreased by 100 % of the $ET_c$ for the treatments 24 and 36 ton $ha^{-1}$compost. While applying 0 and 12 ton $ha^{-1}$of compost with 100 % of the $ET_c$ increased it. The interaction between (36 ton $ha^{-1}$compost rate + 80 % of the $ET_c$ of water regime) achieved the highest number of potato tubers per plant. On the other hand, the interaction between (none compost + 60 % of the $ET_c$ of water regime) gave the lowest value of number of potato tubers per plant (table 19).

In respect of the effect of the double interaction between compost and mulch on number of potato tubers per plant, data in table (20) revealed that increasing compost rates with and without soil covering significantly increased average number of potato tubers per plant. It was noted that except for 24 and 36 ton $ha^{-1}$in mulched soil, the increase in the average number of potato tubers per plant was insignificant. On the other hand, soil mulching decreased the average number of potato tubers per plant with incorporating all compost rates compared to none mulched soil. The maximum number of potato tubers per plant was attained from compost rates at 36 ton $ha^{-1}$in none mulched soil, while the minimum number of potato tubers per plant was obtained without compost by soil covering.

Obtained results in table (21) indicated the influence of the triple interaction among water regimes, mulch and compost rates on average number of potato tubers per plant. Increment in applied water with increasing applied compost rates increased the average number of potato tubers per plant in non-mulched soils. Except for the combination of compost rate at 36 ton $ha^{-1}$+ 100 % of the $ET_c$, water applied reduced the average number of potato tubers per plant. However, soil mulching reduced the average number of potato tubers per plant with all incorporating compost rates under all water irrigation levels compared to none mulched soil. Except for the interaction (60 % of the $ET_c$ water regime +soil mulching + without compost), the interaction (100 % of the $ET_c$ water regime + soil mulching + applying compost rate of 24 ton $ha^{-1}$) and the interaction (100 % of the $ET_c$ water regime + soil mulching + applying compost rate of 36 ton $ha^{-1}$), the average number of potato tubers per plant was increased.

The maximum number of potato tubers per plant was obtained by the combination of (80 % of the $ET_c$ water regime + without soil mulching + applying compost at 36 ton $ha^{-1}$). On the other hand, the minimum number of potato tubers per plant was recorded by the combination of (60 % of the $ET_c$ water regime + without soil mulching + without applying compost).

#### ***5.1.3.2. Average potato tuber weight (kg) and yield per plant (kg):-***

##### ***5.1.3.2.1. General effect of individual factors:-***

Data illustrated in figures (20 and 22) showed the effect of incorporating compost at three rates (12, 24 and 36 ton $ha^{-1}$) compared to that of the soil didn't receive compost on response of both yield components under study. It could be detected that incorporating compost in the soil increased the average potato tuber weight and the average yield per plant compared to the soil that was not treated with compost.

The more the amount of applied compost was, the higher was either the average potato tuber weight or the yield per plant. In other words, increments in average potato weight of the plants treated with compost, compared to that of the plants that didn't receive compost were 18.56, 28.86 and 31.96 % for the application rates of compost 12, 24 and 36 ton $ha^{-1}$, respectively. Related increments in values of average yield per plant were 33.2, 52.5 and 59.8 % in sequence.

Obtained results for response of both yield components (average potato tuber weight and average yield per plant at harvest) explained that soil mulching significantly increased the values of potato tuber weight. Comparing average potato tuber weight for plants grown in the mulched soil to that of the non-mulched one, the average potato tuber weight in the former was higher than that of the latter by 3.5%. Regarding average yield per plant for plants grown in mulched soil, it insignificantly decreased by only 1.0 %.

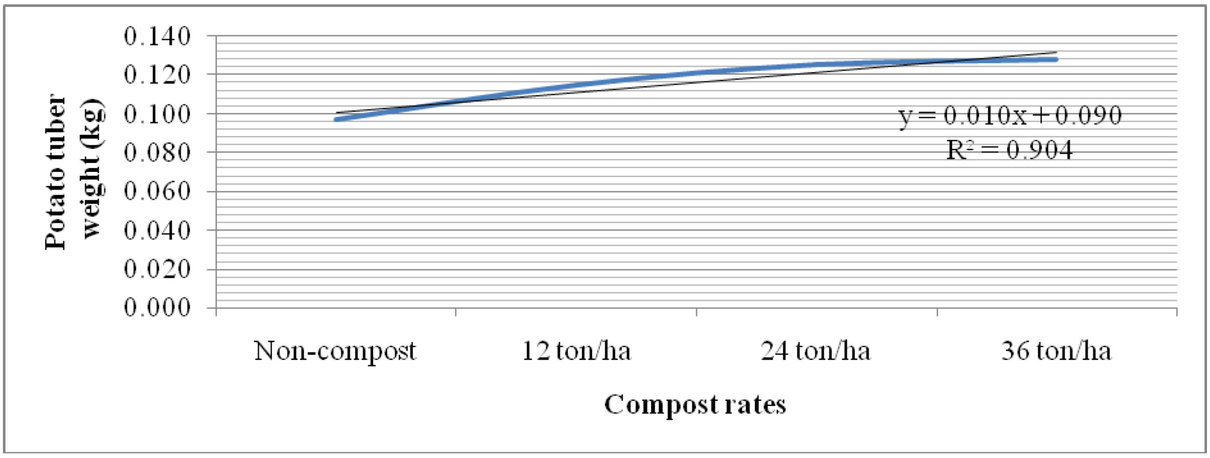


**Fig.(20): Effect of compost rates on average potato tuber weight**

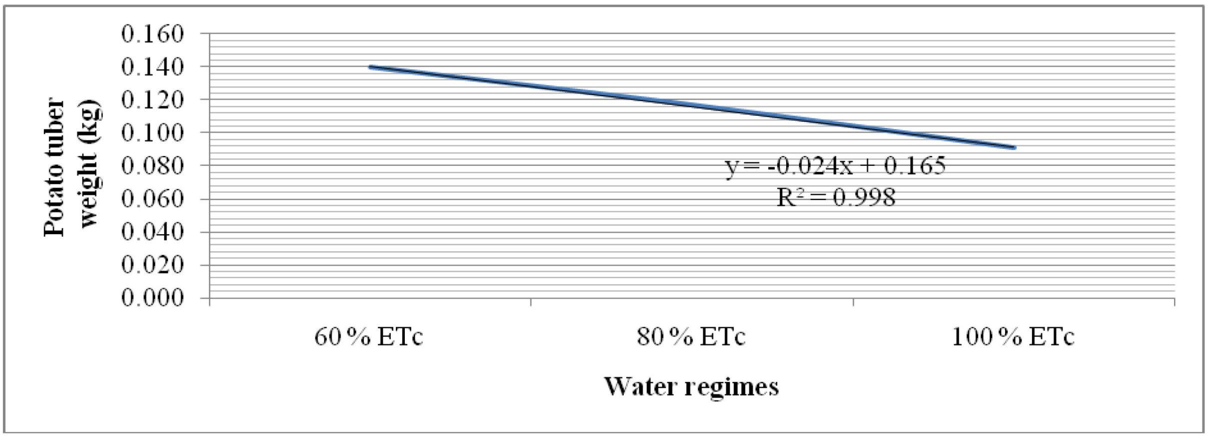


**Fig. (21): Effect of water regimes on average potato tuber weight**

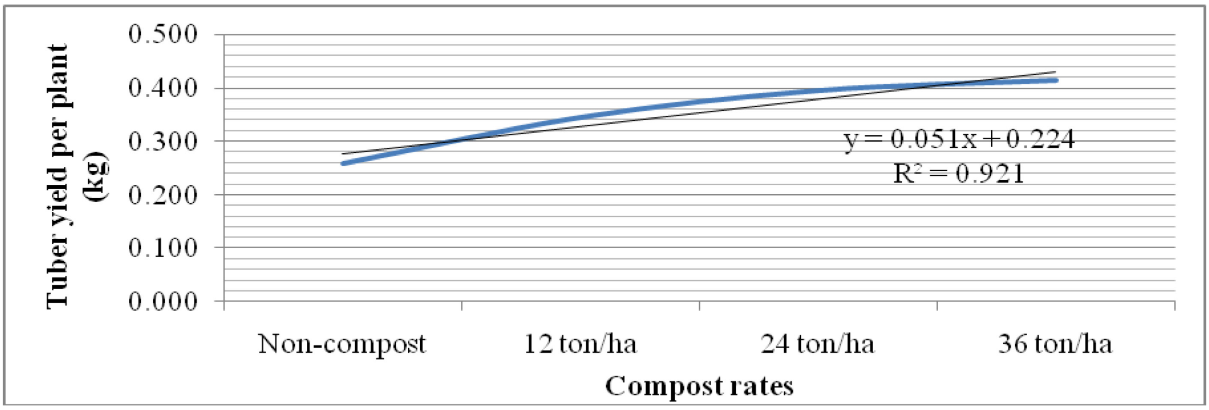


**Fig.(22): Effect of compost rates on tuber yield per plant**

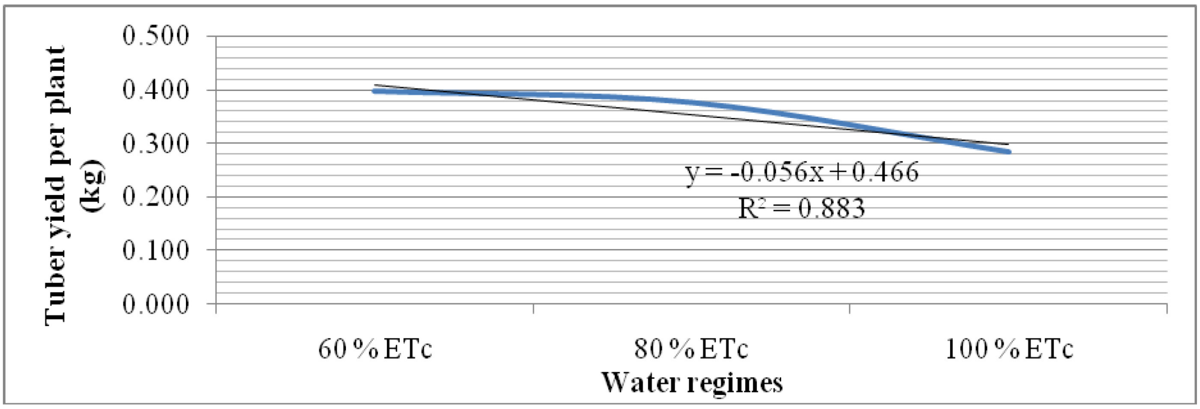


**Fig.(23): Effect of water regimes on tuber yield per plant**

On the contrary, data shown in figures (21 and 23) explained that either average potato tuber weight or average yield per plant gradually decreased with increasing applied irrigation water from 60 % of the $ET_c$ to 100% of the $ET_c$. As applying the quantity of irrigation water equals to the 100 % of the $ET_c$ gave the lowest average potato tuber weight accompanied with the lowest average yield per plant. In other words, the decrement in average potato tuber weight by increasing applied water summed to 16.43 and 35.0 % for water regimes using 80% and 100% of the $ET_{crop}$. The same is true for the average yield per plant, relevant values are 5.3 and 28.4 % that of the irrigated soil with 60 % of the $ET_{crop}$.

***5.1.3.2.2. Effect of interactions among the studied factors on average potato tuber weight and yield per plant :-***

Tables (18-21) showed the influence of the double and triple interactions between water regimes, mulch and compost on potato tuber weight and yield per plant.

As for data in table (18), it could be observed that concerning the effect of the interaction between water regime and mulch on average potato tuber weight and yield per plant, decreasing water regime with mulch increased potato tuber weight and yield per plant. The highest values of potato tuber weight and yield per plant were attained under 60 % of the $ET_c$ water regime in mulched soil while the lowest values were obtained from 100 % of the $ET_c$ water regime in mulched soil.

**Table (18): Effect of the interaction between water regimes and soil mulching on potato tuber yield and its components**

| Water regime | Mulch | Average number of tubers per plant | Average potato tuber weight (kg) | Tuber yield per plant (kg) | Total tuber yield (ton $ha^{-1}$) |
|---|---|---|---|---|---|
| **100 % of $ET_c$*** | **Non-mulch** | 3.21 | 0.096 | 0.305 | 20.374 |
| | **Mulch** | 3.06 | 0.086 | 0.264 | 17.603 |
| **80 % of $ET_c$** | **Non-mulch** | 3.25 | 0.113 | 0.370 | 24.667 |
| | **Mulch** | 3.17 | 0.120 | 0.384 | 25.583 |
| **60 % of $ET_c$** | **Non-mulch** | 2.92 | 0.131 | 0.389 | 25.930 |
| | **Mulch** | 2.72 | 0.148 | 0.408 | 27.194 |
| **LSD at 5%** | | **0.004** | **0.05** | **0.005** | **0.467** |
| **LSD at 1%** | | **0.083** | **0.0001** | **0.008** | **0.708** |

* = 4000 $m^3$/ha

The obtained results illustrated in table (19) demonstrated noticeable influences for the interaction between water regime and compost on average potato tuber weight and average yield per plant. In detail, decreasing irrigation water levels combined with increasing applied compost rates led to increase in potato tuber weight and yield per plant, except for the combination of 100 % of the $ET_c$ applied water + 36 ton $ha^{-1}$compost rate. Applying 36 ton $ha^{-1}$of compost under 60 % of the $ET_c$ water regime achieved the highest values of potato tuber weight and yield per plant. On the other hand, soil which didn't receive compost under 100 % of the $ET_c$ water regime gave the lowest values of potato tuber weight and yield per plant.

In connection with the effect of the double interaction between compost and mulch on potato tuber weight and yield per plant, data shown in table (20) revealed that increasing applied compost rates with soil covering noticeably produced escalating increase in average potato tuber weight and average yield per plant. Increasing applied compost rate from 0 to 12 ton ha$^{-1}$with soil covering significantly raised average potato tuber weight and average yield per plant compared to applying compost at the same rates without soil covering. But the increases in both yield components were declining by increasing compost rates with soil covering. In addition the difference in average potato tuber weight was slight between applied compost rate at 24 and 36 ton ha$^{-1}$in mulched soil. This may be lead us to that applied compost rate at 24 ton ha$^{-1}$ in mulched soil, was the best double interaction between compost and mulch.

**Table (19): Effect of the interaction between water regime and compost on potato tuber yield and its components**

| Water regime | Compost (ton ha$^{-1}$) | Average number of tubers per plant | Average potato tuber weight (kg) | Tuber yield per plant (kg) | Total tuber yield (ton ha$^{-1}$) |
|---|---|---|---|---|---|
| 100 % of $ET_c$* | Non-compost | 3.16 | 0.073 | 0.231 | 15.39 |
| | 12 | 3.17 | 0.088 | 0.280 | 18.65 |
| | 24 | 3.18 | 0.099 | 0.317 | 21.11 |
| | 36 | 3.02 | 0.103 | 0.312 | 20.81 |
| 80 % of $ET_c$ | Non-compost | 2.99 | 0.099 | 0.296 | 19.72 |
| | 12 | 3.10 | 0.114 | 0.352 | 23.45 |
| | 24 | 3.26 | 0.126 | 0.411 | 27.42 |
| | 36 | 3.50 | 0.128 | 0.449 | 29.92 |
| 60 % of $ET_c$ | Non-compost | 2.12 | 0.118 | 0.250 | 16.67 |
| | 12 | 2.85 | 0.142 | 0.405 | 26.97 |
| | 24 | 3.10 | 0.148 | 0.456 | 30.41 |
| | 36 | 3.21 | 0.151 | 0.483 | 32.20 |
| **LSD at 5%** | | **0.064** | **0.0002** | **0.0001** | **0.394** |
| **LSD at 1%** | | **0.086** | **0.0002** | **0.0001** | **0.527** |

* = 4000 m³/ha

The highest values of potato tuber weight and yield per plant were attained from applied compost rates at 36 ton ha$^{-1}$in non-mulched soil. However, the lowest values were obtained from non mulched soil that didn't receive compost.

Obtained results in table (21) and fig. (24-25) indicated that the triple interaction among water regimes, mulch and compost rates resulted in significant differences in potato tuber weight and yield per plant. In other words, the decrement in applied water with increasing applied compost rates increased potato tuber weight and yield per plant in mulched and non mulched soils. Excluding 100 % of the $ET_c$ water applied, yield per plant was reduced by all incorporating compost rates in the mulched soil compared to non mulched soil. Highly negative effect for yield per plant was observed without compost under 100 % of the $ET_c$ water irrigation level in mulched soil, while the same effect was noticed for potato tuber weight in non mulched soil.

**Table (20): Effect of the interaction between soil mulching and compost on potato tuber yield and its components**

| Mulch | Compost (ton $ha^{-1}$) | Average number of tubers per plant | Average potato tuber weight (kg) | Tuber yield per plant (kg) | Total tuber yield (ton $ha^{-1}$) |
|---|---|---|---|---|---|
| Non-mulch | Non-compost | 2.84 | 0.093 | 0.254 | 16.96 |
| | 12 | 3.12 | 0.111 | 0.343 | 22.87 |
| | 24 | 3.22 | 0.123 | 0.396 | 26.39 |
| | 36 | 3.31 | 0.128 | 0.426 | 28.41 |
| Mulch | Non-compost | 2.68 | 0.101 | 0.263 | 17.56 |
| | 12 | 2.95 | 0.119 | 0.347 | 23.18 |
| | 24 | 3.14 | 0.126 | 0.393 | 26.24 |
| | 36 | 3.18 | 0.127 | 0.403 | 26.87 |
| **LSD at 5%** | | **0.052** | **0.001** | **0.005** | **0.322** |
| **LSD at 1%** | | **0.070** | **0.002** | **0.006** | **0.430** |

Therefore, the highest values for potato tuber weight and yield per plant were obtained by the combination between 60 % of the $ET_c$ water regime, soil mulching and applying 36 ton $ha^{-1}$compost. On the other hand, the lowest values were recorded without compost in non mulched soil for potato tuber weight and in mulched soil for yield per plant under 100 % of the $ET_c$ water regime.

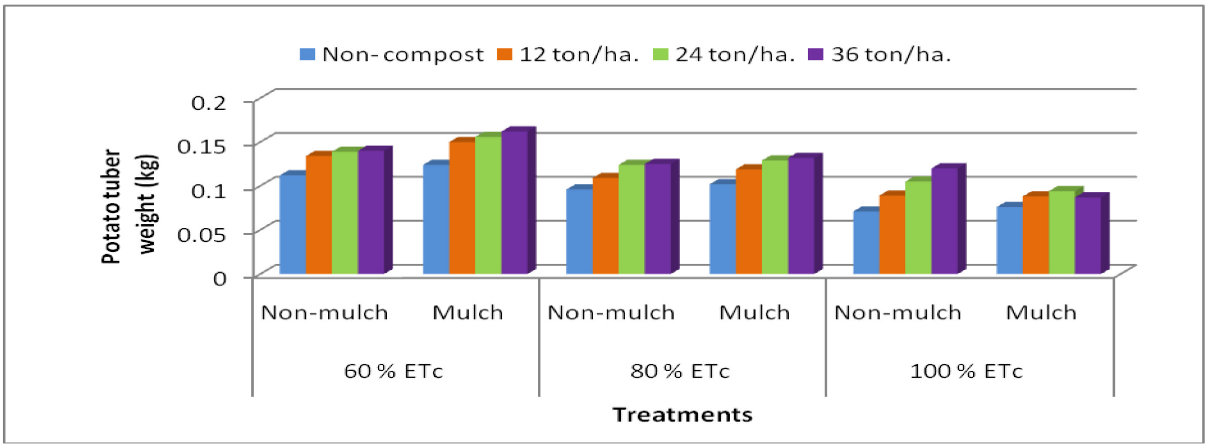


**Fig. (24): Effect of the interaction among water regimes, mulch and compost on potato tuber weight**

**Table (21): Effect of the interaction among water regimes, mulch and compost on potato tuber yield components**

| Property | Water regime | Mulch | Compost (ton $ha^{-1}$) | | | |
|---|---|---|---|---|---|---|
| | | | Non-compost | 12 | 24 | 36 |
| Tuber yield per plant (kg) | 100 % of $ET_{c}$* | Non-mulch | 0.241 | 0.290 | 0.332 | 0.359 |
| | | Mulch | 0.221 | 0.269 | 0.301 | 0.265 |
| | 80 % of $ET_c$ | Non-mulch | 0.289 | 0.344 | 0.403 | 0.443 |
| | | Mulch | 0.302 | 0.359 | 0.419 | 0.454 |
| | 60 % of $ET_c$ | Non-mulch | 0.233 | 0.395 | 0.451 | 0.476 |
| | | Mulch | 0.266 | 0.414 | 0.461 | 0.490 |
| LSD at 5% | | | 0.001 | | | |
| LSD at 1% | | | 0.001 | | | |
| Average potato tuber weight (kg) | 100 % of $ET_c$ | Non-mulch | 0.071 | 0.089 | 0.105 | 0.120 |
| | | Mulch | 0.076 | 0.088 | 0.094 | 0.087 |
| | 80 % of $ET_c$ | Non-mulch | 0.096 | 0.109 | 0.124 | 0.125 |
| | | Mulch | 0.102 | 0.119 | 0.129 | 0.132 |
| | 60 % of $ET_c$ | Non-mulch | 0.112 | 0.134 | 0.139 | 0.140 |
| | | Mulch | 0.124 | 0.150 | 0.156 | 0.162 |
| LSD at 5% | | | 0.003 | | | |
| LSD at 1% | | | 0.003 | | | |
| Average number of tubers per plant | 100 % of $ET_c$ | Non-mulch | 3.41 | 3.26 | 3.17 | 2.99 |
| | | Mulch | 2.91 | 3.07 | 3.20 | 3.06 |
| | 80 % of $ET_c$ | Non-mulch | 3.02 | 3.16 | 3.26 | 3.55 |
| | | Mulch | 2.96 | 3.03 | 3.26 | 3.45 |
| | 60 % of $ET_c$ | Non-mulch | 2.08 | 2.94 | 3.24 | 3.40 |
| | | Mulch | 2.16 | 2.76 | 2.95 | 3.03 |
| LSD at 5% | | | 0.090 | | | |
| LSD at 1% | | | 0.121 | | | |

*= 4000 m³/ha

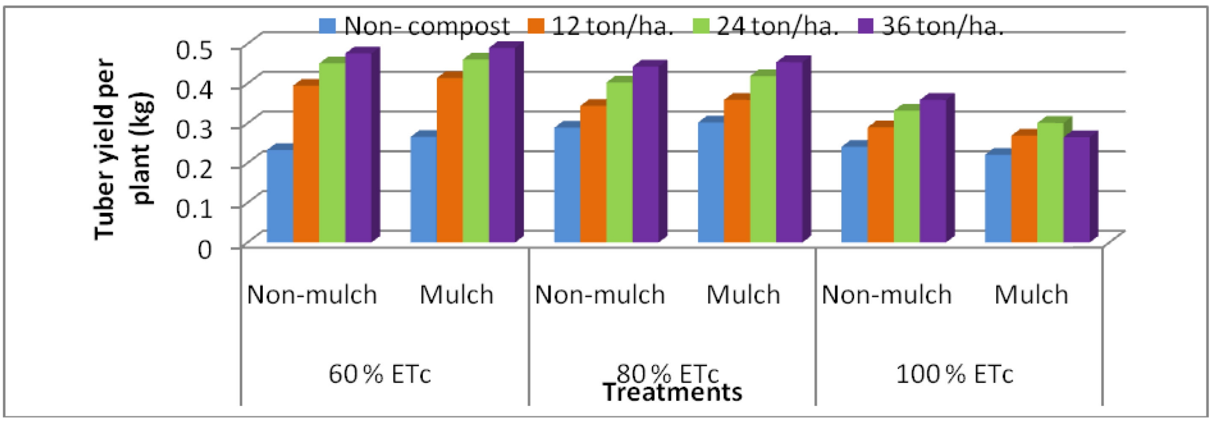


**Fig.(25): Effect of the interaction among water regimes, mulch and compost on tuber yield per plant**

### 5.1.4. <u>*Effect on total potato tuber yield (ton $ha^{-1}$):-*</u>

Values of total tuber yield ranged about 23.56(±5.6). However, the triple interaction for 60 % of $ET_c$ water regime + 36 ton $ha^{-1}$compost + mulch produced the highest value (32.67 ton $ha^{-1}$). Data of total potato tuber yield as affected by applying compost and mulch under drip irrigation regimes are shown in the following:-

#### 5.1.4.1. *General effect of the individual factors on total potato tuber yield :-*

As for the data shown in figure (26), compost rates had high significance on total yield of potato. Thoroughly, applying 12, 24 and 36 ton $ha^{-1}$of compost increased total yield of potato plants by 33.37 %, 52.43 %, and 60.14 %, respectively over that of potato plants grown in soils that didn't receive compost.

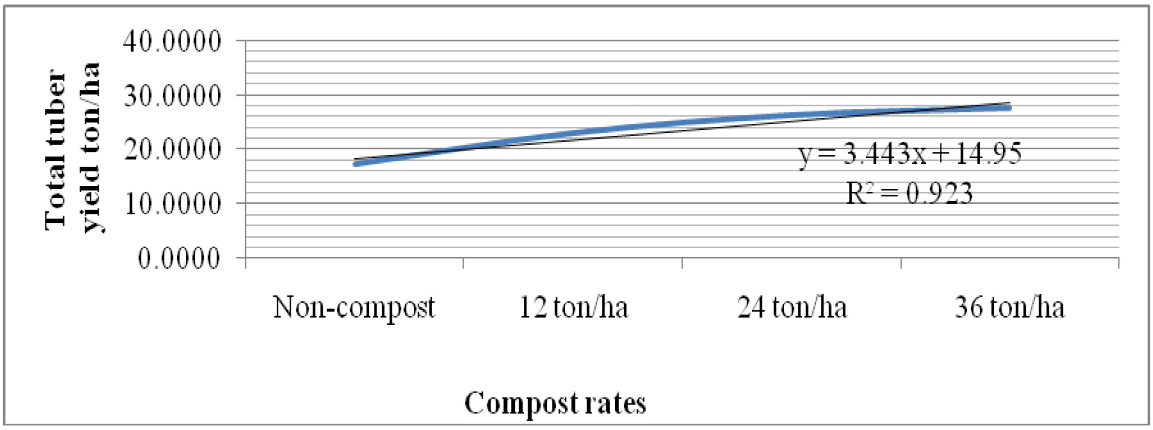


**Fig.(26): Effect of compost rates on total tuber yield ton/ha**

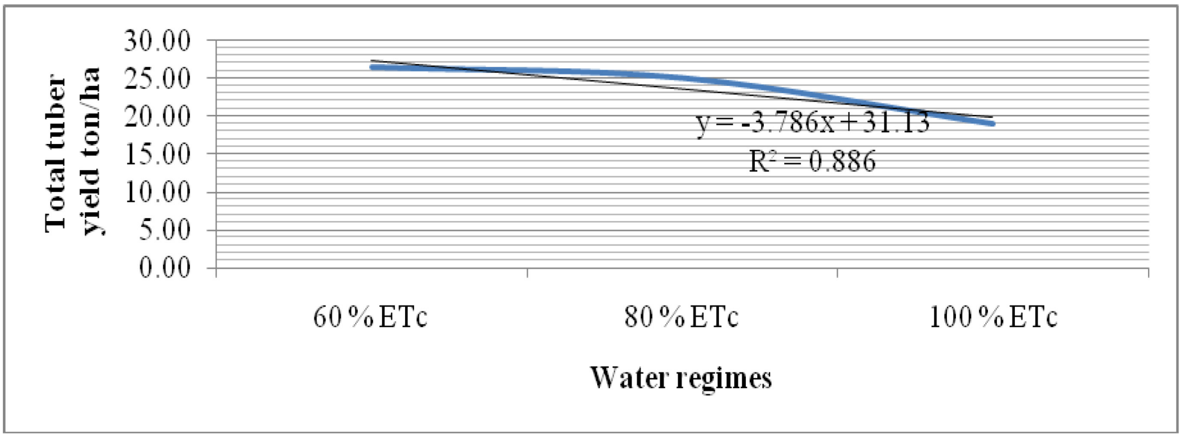


**Fig.(27): Effect of water regimes on total tuber yield**

In contrast, it could be concluded that generally soil mulching insignificantly reduced the total tuber yield. Comparing the total tuber yield for plants in the mulched soil to that in the non-mulched one, the average value of the former was 99.15 % that of the latter.

Concerning water regimes effect as presented in figure (27), it could be observed that, in general, total tuber yield was increased by decreasing water irrigation level. In detail, the increments were 32.33 and 39.86 % for 80 and 60 % of the $ET_c$ compared to 100 % of the $ET_c$ water regime, respectively.

### *5.1.4.2. <u>Effect of interactions among the studied factors on total potato tuber yield:-</u>*

Tables (18-20, 22) showed the influence of the double and triple interactions between water regimes, mulch and compost on total potato tuber yield.

As regards the interaction between water regime and mulch (table 18 and fig. 28), it could be noticed that decreasing water regimes with mulch raised the total potato tuber yield. The highest value of total potato tuber yield was achieved by 60 % of the $ET_c$ water regime in mulched soil, while the lowest value of total potato tuber yield was recorded by 100 % of the $ET_c$ water regime in mulched soil.

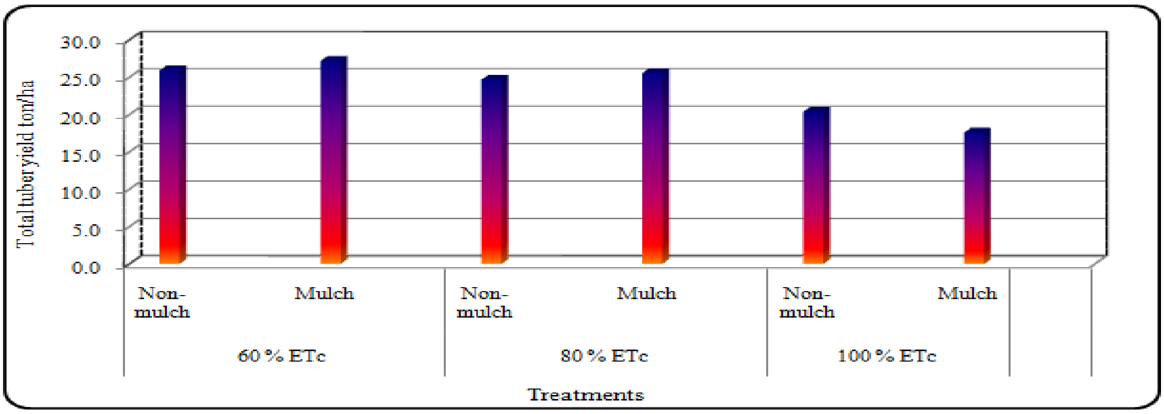


**Fig.(28): Effect of the interaction between water regimes and soil mulching on total tuber yield**

Referring to the effect of the double interaction between water regime and compost on total potato tuber yield, obtained results represented in table (19) and figure (29) indicated that decreasing irrigation water levels combined with increasing applied compost led to a significant increase in total tuber yield, except for the combination of 100 % of the $ET_c$ applied water and 36 ton $ha^{-1}$compost. Insignificant difference was observed between applying 36 and 24 ton compost $ha^{-1}$. Incorporating 36 ton $ha^{-1}$compost in soil under 60 % of the $ET_c$ water regime achieved the highest value (32.20 ton $ha^{-1}$) of total tuber yield. On the other hand, none compost under 100 % of the $ET_c$ water regime gave the lowest value (15.39 ton $ha^{-1}$).

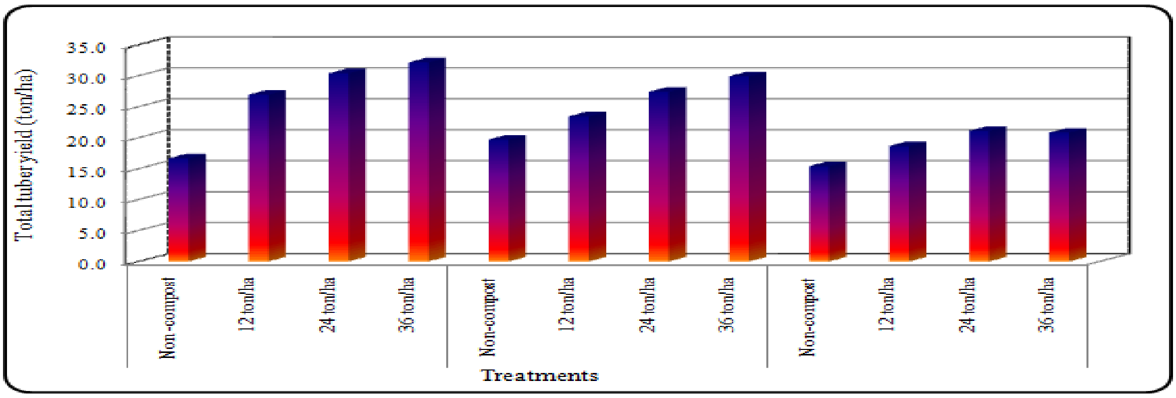


**Fig.(29): Effect of the interaction between water regime and compost on total tuber yield**

Concerning the effect of the double interaction between compost and mulch on the total potato tuber yield, data in table (20) and figure (30) detected that increasing applied compost from 0 to 12 ton $ha^{-1}$ considerably increased total tuber yield in mulched soil compared to that when applying compost at the same rate in non mulched one. But this increment in total tuber yield was declining by applying compost in mulched soil; in addition the difference was slight between applying 24 and 36 ton $ha^{-1}$ of compost.

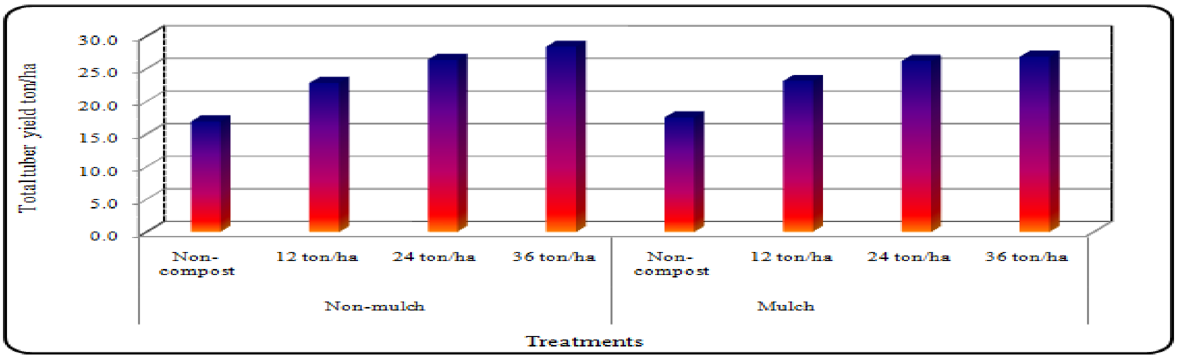


**Fig.(30): Effect of the interaction between soil mulching and compost on total tuber yield**

The highest value of total tuber yield (28.4 ton $ha^{-1}$) was achieved by applying 36 ton $ha^{-1}$ of compost in none mulched soil, while the lowest value (16.96 ton $ha^{-1}$) was obtained from none mulched soil that didn't receive compost.

As for data in table (22) and figure (31), there were significant effects of the triple interaction among water regimes, mulch and compost rates on total tuber yield. Even though a positive effect of water regimes had been detected by the treatments without mulch and compost through increasing water irrigation level from 60 % of the $ET_c$ to 80% of the $ET_c$, the negative effect was observed by 100 % of the $ET_c$ water irrigation level. In other words, the decrement in applied water with increasing applied compost rates increased total tuber yield in mulched and non mulched soils except for 100 % of the $ET_c$, soil mulching reduced total tuber yield with all incorporating compost rates compared to the non-mulched soil. The highly negative effect, for total tuber yield, was obtained from the treatment without compost under 100 % of the $ET_c$ water irrigation level in mulched soil.

**Table (22): Effect of the interaction among water regimes, mulch and compost on total potato tuber yield**

| Property | Water regime | Mulch | Compost (ton $ha^{-1}$) | | | |
|---|---|---|---|---|---|---|
| | | | Non-compost | 12 | 24 | 36 |
| Total tuber yield (ton $ha^{-1}$) | 100 % of $ET_{c*}$ | Non-mulch | 16.05 | 19.33 | 22.17 | 23.94 |
| | | Mulch | 14.72 | 17.97 | 20.06 | 17.67 |
| | 80 % of $ET_c$ | Non-mulch | 19.28 | 22.94 | 26.89 | 29.56 |
| | | Mulch | 20.17 | 23.95 | 27.94 | 30.28 |
| | 60 % of $ET_c$ | Non-mulch | 15.56 | 26.33 | 30.11 | 31.72 |
| | | Mulch | 17.78 | 27.61 | 30.72 | 32.67 |
| | LSD at 5% | | 0.557 | | | |
| | LSD at 1% | | 0.745 | | | |

* = 4000 $m^3$/ha

The highest value of total tuber yield (32.67 ton $ha^{-1}$) was achieved by the combination of (60 % of the $ET_c$ water regime + soil mulching + applying 36 ton $ha^{-1}$compost). In contrast, the lowest value of total tuber yield (14.7 ton $ha^{-1}$) was recorded by the combination of (100 % of the $ET_c$ water regime + soil mulching + non compost).

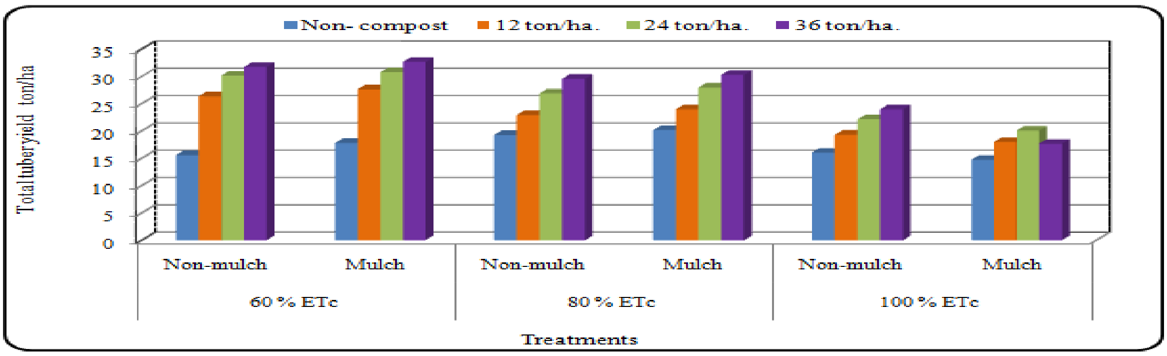


**Fig.(31): Effect of the interaction among water regimes, mulch and compost on total tuber yield ton/ha**

### *5.2. <u>Effect of treatments on hydrophysical properties of the soil:-</u>*

#### *5.2.1. <u>Effect of treatments on soil bulk density, void ratio, total porosity, and pore size distribution:</u>*

The effect of applying compost, soil mulching and water regime on soil bulk density (gm $cm^{-3}$), void ratio, total porosity (%) and pore size distribution (as a percentage of total porosity) are given in tables (23 - 28), respectively. Figures (32 - 44) illustrated the effect of the aforementioned on the studied soil characteristics. Data revealed the following:-

#### *5.2.1.1. <u>Effect of treatments on soil bulk density (gm $cm^{-3}$ ):</u>*

Incorporating compost in the soil significantly decreased its bulk density, compared to the soil that didn't receive compost. The more the amount of applied compost was, the lower was the bulk density of soil. Decrements in soil bulk density of the soil treated with compost were 11.5, 18.9 and 21.4 %, respectively (Fig. 32).

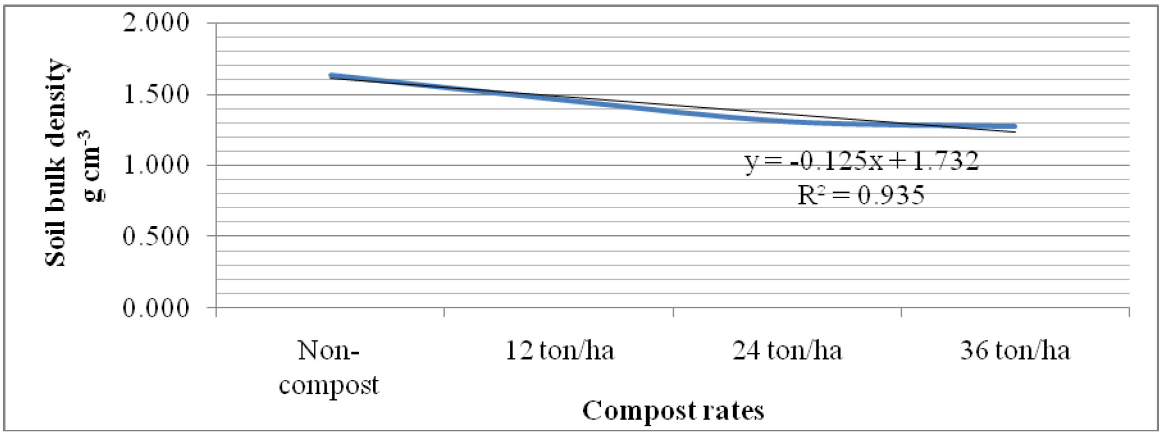


**Fig.(32): Effect of compost on soil bulk density**

Moreover, soil mulching generally reduced soil bulk density under all treatments of applying compost and water regimes. Comparing the bulk density of the mulched soil to that of the non-mulched one, bulk density of the former was lower than that of the latter by about 2 %.

Regarding the effect of water regimes on soil bulk density, data in hand reveal that increasing applied water to the soil decreased its bulk density. In detail, values of bulk density of the soil were 99.3 and 99.0 % that of the soil received 60 % of its $ET_c$ for the soils that received 80 % and 100 % of their $ET_c$, in sequence (Fig. 33).

Table (23): Effect of compost and mulch on bulk density (g $cm^{-3}$) under different water regimes

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 1.640 | 1.633 | **1.637** |
| | 12 ton/ha | 1.490 | 1.435 | **1.463** |
| | 24 ton/ha | 1.325 | 1.288 | **1.307** |
| | 36 ton/ha | 1.280 | 1.263 | **1.272** |
| | Mean | **1.434** | **1.405** | **1.419** |
| 80 % of $ET_c$ | Non-compost | 1.640 | 1.625 | **1.633** |
| | 12 ton/ha | 1.460 | 1.420 | **1.440** |
| | 24 ton/ha | 1.363 | 1.325 | **1.344** |
| | 36 ton/ha | 1.285 | 1.273 | **1.279** |
| | Mean | **1.437** | **1.411** | **1.424** |
| 60 % of $ET_c$ | Non-compost | 1.655 | 1.635 | **1.645** |
| | 12 ton/ha | 1.468 | 1.423 | **1.446** |
| | 24 ton/ha | 1.350 | 1.318 | **1.334** |
| | 36 ton/ha | 1.325 | 1.300 | **1.313** |
| | Mean | **1.450** | **1.419** | **1.434** |
| | Mean | **1.440** | **1.412** | |
| Grand mean | | | | **1.426** |

| Mean of compost | | | | |
|---|---|---|---|---|
| Compost | Water regime | | | Mean |
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| Non-compost | 1.637 | 1.633 | 1.645 | **1.638** |
| 12 ton/ha | 1.463 | 1.440 | 1.446 | **1.449** |
| 24 ton/ha | 1.307 | 1.344 | 1.334 | **1.328** |
| 36 ton/ha | 1.272 | 1.279 | 1.313 | **1.288** |
| Mean | **1.419** | **1.424** | **1.434** | **1.426** |

* = 4000 $m^3$/ha

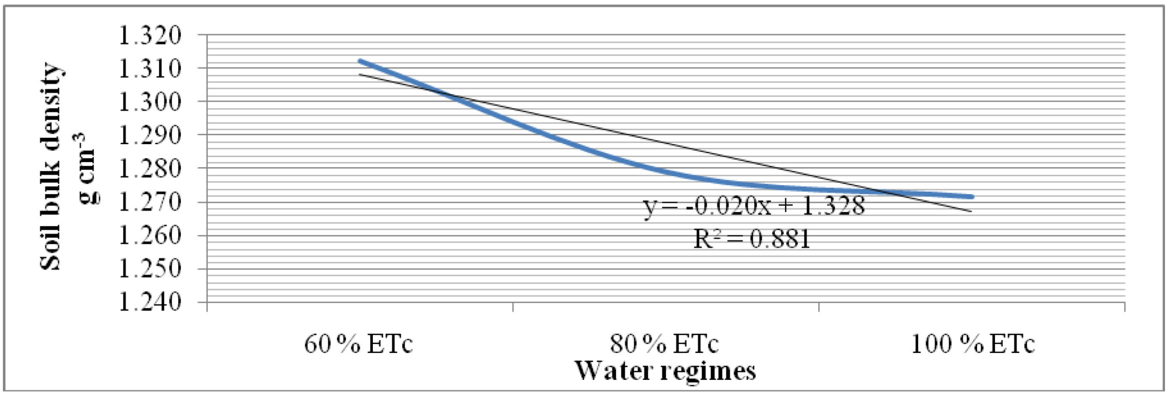


Fig.(33): Effect of water regimes on soil bulk density

### 5.2.1.2. ***Effect of treatments on void ratio:-***

Applying compost in the soil amplified its void ratio, compared to the soil that didn't receive compost. The more the amount of applied compost was, the higher was the void ratio. In other words, increments in void ratio of the soil treated with compost, compared to that of the soil didn't receive compost were 34.5, 61.45 and 71.3 % for the applying 12, 24 and 36 ton $ha^{-1}$ of compost, respectively (Fig. 34).

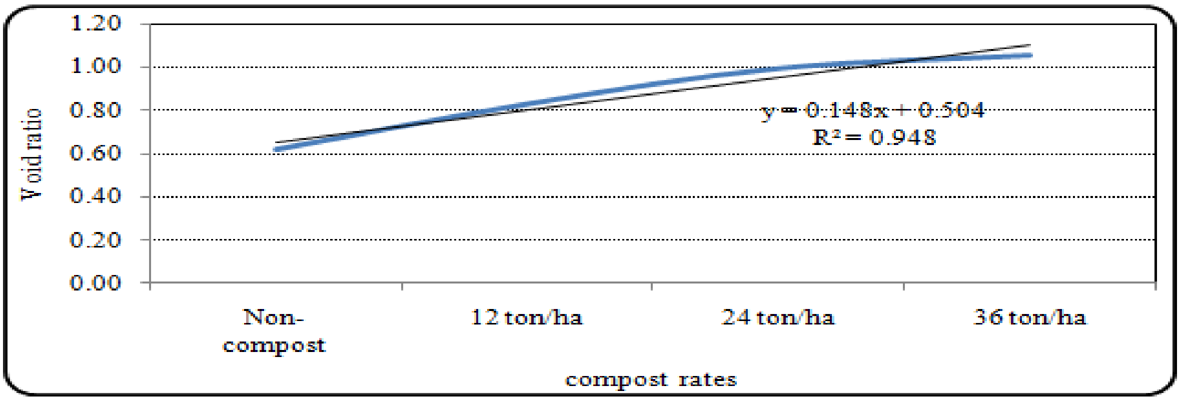


**Fig.(34): Effect of compost rates on void ratio**

In addition, soil mulching generally increased the values of void ratio under all treatments of applying compost and water regimes. Comparing the void ratio of the mulched soil to that of the non-mulched one, void ratio of the former was higher than that of the latter by 4.5%.

Concerning the effect of water regimes on void ratio, data in hand declare that increasing applied water to the soil increased its void ratio. In detail, increases in void ratio were 1.9 and 3.0 % that of the soil received 60 % of its $ET_c$ for the soils that received 80 % and 100 % of their $ET_c$, in sequence (fig. 35).

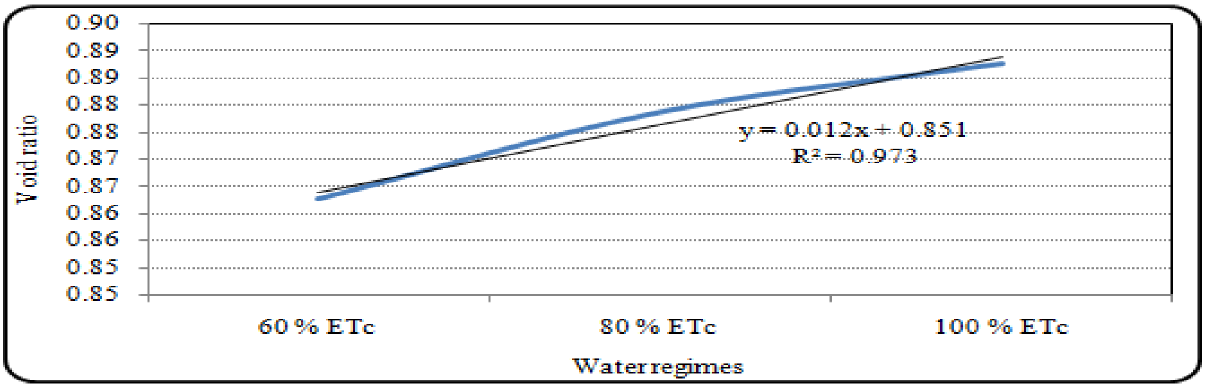


**Fig.(35): Effect of water regimes on void ratio**

**Table (24): Effect of compost and mulch on void ratio under different water regimes**

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 0.62 | 0.62 | **0.62** |
| | 12 ton/ha | 0.78 | 0.85 | **0.81** |
| | 24 ton/ha | 1.00 | 1.07 | **1.03** |
| | 36 ton/ha | 1.07 | 1.10 | **1.08** |
| | Mean | **0.87** | **0.91** | **0.89** |
| 80 % of $ET_c$ | Non-compost | 0.62 | 0.63 | **0.62** |
| | 12 ton/ha | 0.83 | 0.87 | **0.85** |
| | 24 ton/ha | 0.94 | 1.00 | **0.97** |
| | 36 ton/ha | 1.06 | 1.08 | **1.07** |
| | Mean | **0.86** | **0.89** | **0.88** |
| 60 % of $ET_c$ | Non-compost | 0.60 | 0.62 | **0.61** |
| | 12 ton/ha | 0.81 | 0.86 | **0.83** |
| | 24 ton/ha | 0.96 | 1.01 | **0.99** |
| | 36 ton/ha | 1.00 | 1.04 | **1.02** |
| | Mean | **0.84** | **0.88** | **0.86** |
| | Mean | **0.86** | **0.90** | |
| Grand mean | | | | **0.88** |

| Mean of compost | | | | |
|---|---|---|---|---|
| Compost | Water regime | | | Mean |
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| Non-compost | 0.62 | 0.62 | 0.61 | **0.62** |
| 12 ton/ha | 0.81 | 0.85 | 0.83 | **0.83** |
| 24 ton/ha | 1.03 | 0.97 | 0.99 | **1.00** |
| 36 ton/ha | 1.08 | 1.07 | 1.02 | **1.06** |
| Mean | **0.89** | **0.88** | **0.86** | **0.88** |

* = 4000 $m^3$/ha

### *5.2.1.3. Effect of treatments on total porosity (%):-*

Compared to the soil treated with compost, the more the amount of applied compost was, the higher was the total porosity. Increments in total porosity of were 18.8, 30.61 and 34.6 % for the applying 12, 24 and 36 ton $ha^{-1}$ of compost, respectively ( table 25 and fig. 36).

**Table (25): Effect of compost and mulch on total porosity % under different drip water regimes**

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 38.11 | 38.38 | **38.25** |
| | 12 ton/ha | 43.77 | 45.85 | **44.81** |
| | 24 ton/ha | 50.00 | 51.40 | **50.70** |
| | 36 ton/ha | 51.70 | 52.34 | **52.02** |
| | **Mean** | **45.90** | **46.99** | **46.44** |
| 80 % of $ET_c$ | Non-compost | 38.11 | 38.68 | **38.40** |
| | 12 ton/ha | 45.28 | 46.42 | **45.85** |
| | 24 ton/ha | 48.57 | 50.00 | **49.29** |
| | 36 ton/ha | 51.51 | 51.96 | **51.74** |
| | **Mean** | **45.87** | **46.77** | **46.32** |
| 60 % of $ET_c$ | Non-compost | 37.55 | 38.30 | **37.93** |
| | 12 ton/ha | 44.60 | 46.30 | **45.45** |
| | 24 ton/ha | 49.06 | 50.26 | **49.66** |
| | 36 ton/ha | 50.00 | 50.94 | **50.47** |
| | **Mean** | **45.30** | **46.45** | **45.88** |
| | **Mean** | **45.69** | **46.74** | |
| **Grand mean** | | | | **46.21** |

**Mean of compost**

| Compost | Water regime | | | Mean |
|---|---|---|---|---|
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| **Non-compost** | 38.25 | 38.40 | 37.93 | **38.19** |
| **12 ton/ha** | 44.81 | 45.85 | 45.45 | **45.37** |
| **24 ton/ha** | 50.70 | 49.29 | 49.66 | **49.88** |
| **36 ton/ha** | 52.02 | 51.74 | 50.47 | **51.41** |
| **Mean** | **46.44** | **46.32** | **45.88** | **46.21** |

* = 4000 $m^3$/ha

Moreover, it is noticed that soil mulching generally increased the values of total porosity under all treatments of applying compost and water regimes. Comparing the total porosity of the mulched soil to that of the non-mulched one, total porosity of the former was higher than that of the latter by 2.3 %.

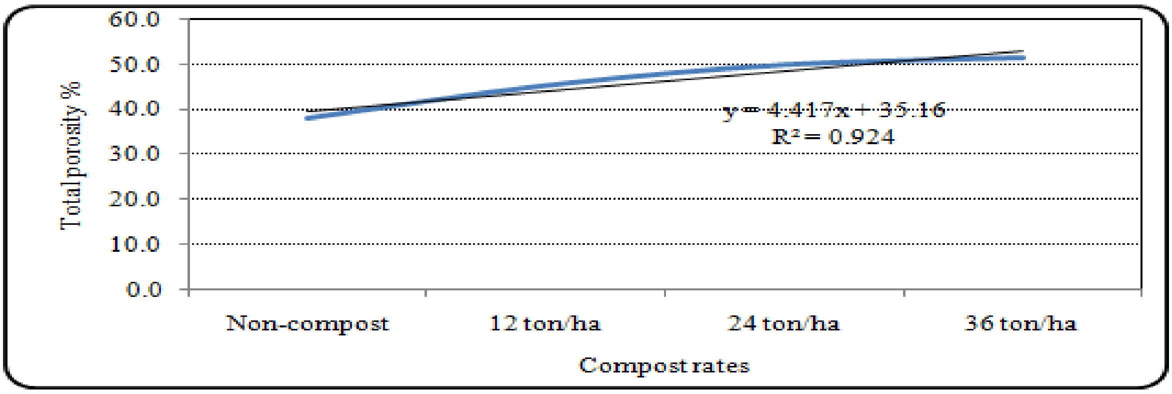


**Fig.(36): Effect of compost on total porosity**

Regarding the effect of water regimes on total porosity, data in hand reveal that increasing applied water to the soil insignificantly increased its total porosity. In details, augments of total porosity were 1.0 and 1.22 % that of the soil received 60 % of its $ET_c$ for the soils that received 80 % and 100 % of their $ET_c$, in sequence.

***5.2.1.4. Effect of treatments on pore size distribution:-***

***5.2.1.4.1. Effect of treatments on drainable pores ( pores > 28.7 µm in diameter):-***

Incorporating compost in the soil reduced its pores > 28.7 µm in diameter. Decrements in pores > 28.7 µm in diameter of the soil treated with compost, compared to that of the soil didn't receive compost were 7.3, 18.4 and 25.1 % for the application rates of compost 12, 24 and 36 ton $ha^{-1}$, respectively (table 26 and fig. 37).

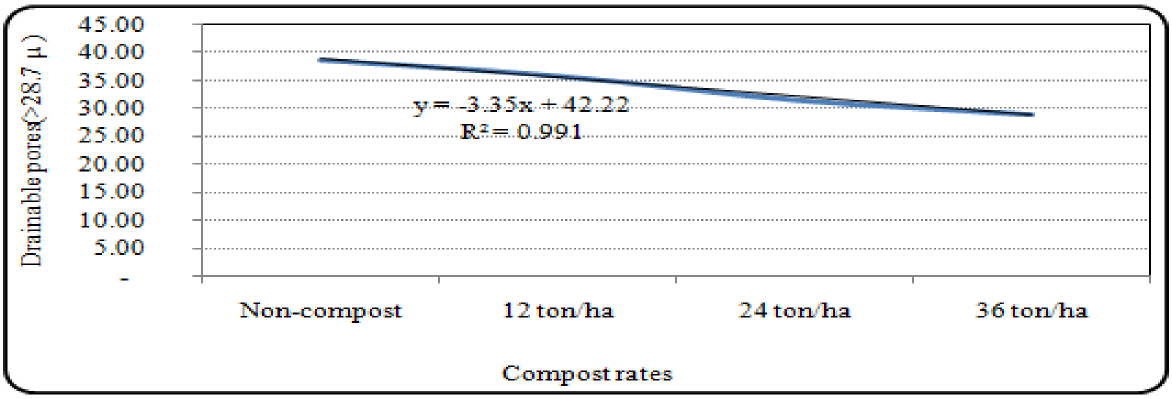


**Fig.(37): Effect of compost on drainable pores**

Furthermore, it can be noticed that soil mulching generally increased the values of pores > 28.7 µm in diameter. Comparing the mulched soil to the non-mulched one, pores > 28.7 µm in diameter of the former was higher than that of the latter by 6.3 %.

**Table (26): Effect of compost and mulch on drainable pores (> 28.7 µ) under different drip water regimes**

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 36.60 | 35.30 | **35.95** |
| | 12 ton/ha | 38.60 | 39.60 | **39.10** |
| | 24 ton/ha | 35.30 | 38.10 | **36.70** |
| | 36 ton/ha | 30.20 | 31.30 | **30.75** |
| | Mean | **35.18** | **36.08** | **35.63** |
| 80 % of $ET_c$ | Non-compost | 38.50 | 41.30 | **39.90** |
| | 12 ton/ha | 35.50 | 36.90 | **36.20** |
| | 24 ton/ha | 27.60 | 33.70 | **30.65** |
| | 36 ton/ha | 31.80 | 30.40 | **31.10** |
| | Mean | **33.35** | **35.58** | **34.46** |
| 60 % of $ET_c$ | Non-compost | 37.10 | 43.80 | **40.45** |
| | 12 ton/ha | 32.30 | 32.80 | **32.55** |
| | 24 ton/ha | 26.30 | 28.90 | **27.60** |
| | 36 ton/ha | 23.90 | 26.6 | **25.25** |
| | Mean | **29.90** | **33.03** | **31.46** |
| | Mean | **32.81** | **34.89** | |
| Grand mean | | | | **33.85** |
| **Mean of compost** | | | | |
| Compost | Water regime | | | Mean |
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| Non-compost | 35.95 | 39.90 | 40.45 | **38.77** |
| 12 ton/ha | 39.10 | 36.20 | 32.55 | **35.95** |
| 24 ton/ha | 36.70 | 30.65 | 27.60 | **31.65** |
| 36 ton/ha | 30.75 | 31.10 | 25.25 | **29.03** |
| Mean | **35.63** | **34.46** | **31.46** | **33.85** |

* = 4000 m³/ha

Concerning the effect of water regimes on pores > 28.7 µm in diameter, data in hand reveal that increasing applied water to the soil decreased its pores > 28.7 µm in diameter. In details, decreases in pores > 28.8 µm in diameter were 3.3 and 11.7 % that of the soil received 100 % of its $ET_c$ for the soils that received 80 % and 60 % of their $ET_c$, in sequence (fig. 38) .

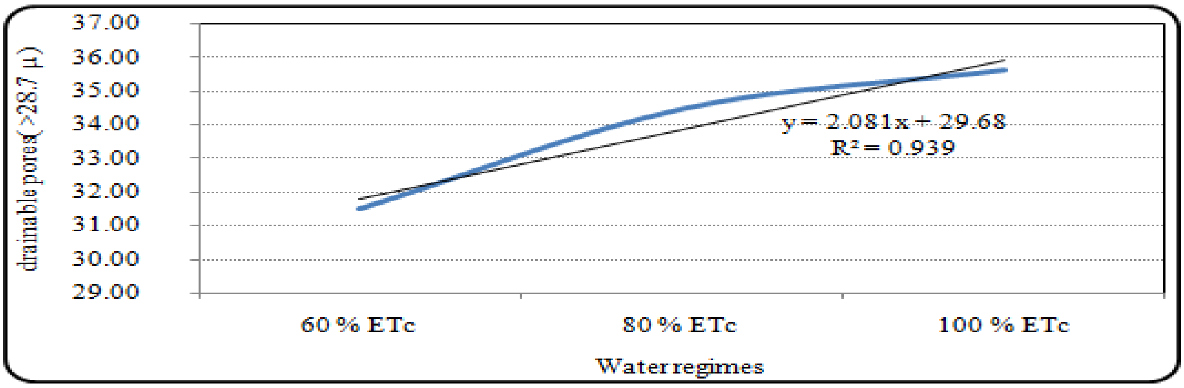


**Fig.(38): Effect of water regimes on drainable pores**

***5.2.1.4.2. <u>Effect of treatments on water holding pores (pores 28.7 – 0.19 µm in diameter):-</u>***

Incorporating compost in the soil enlarged its pores 28.7 – 0.19 µm in diameter, compared to the soil that didn't receive compost. Increments in pores 28.7 – 0.19 µm in diameter of the soil treated with compost, compared to that of the soil didn't receive compost were 6.6, 20.5 and 23.7 % of the application rates of compost 12, 24 and 36 ton $ha^{-1}$, respectively (table 27 and fig. 39).

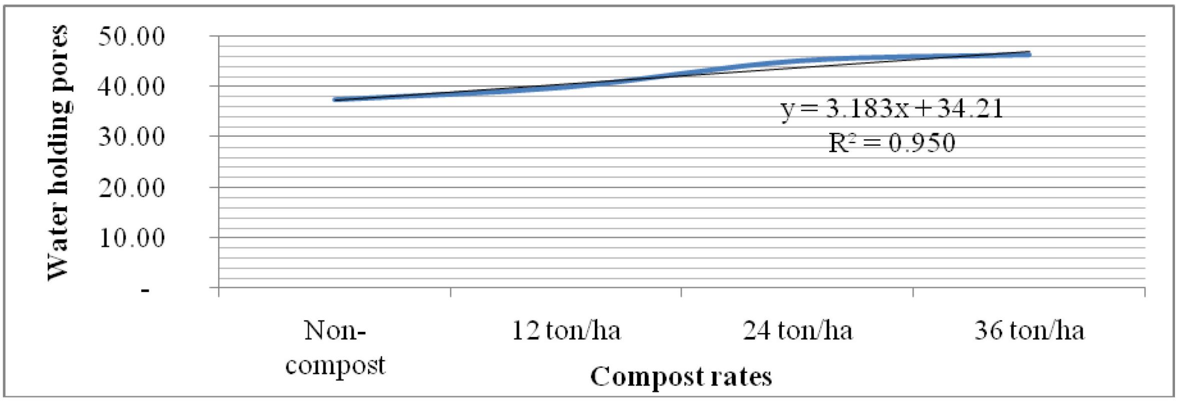


**Fig.(39): Effect of compost on water holding pores**

Moreover, it is noticed that soil mulching generally decreased the values of pores 28.7 – 0.19 µm in diameter. Comparing the pores 28.7 – 0.19 µm in diameter of the mulched soil to that of the non-mulched one, pores 28.7 – 0.19 µm in diameter of the former amount was lower than that of the latter one by 4.5 %. Concerning the effect of water regimes on pores 28.7 – 0.19 µm in diameter (fig. 40), data in hand revealed that increasing applied water to the soil decreased numbers of its pores 28.7 – 0.19 µm in diameter. In detail, values of pores 28.8 – 0.19 µm in diameter were 96.13 and 93.56 % that of the soil received 60 % of its $ET_c$ for the soils that received 80 % and 100 % of their $ET_c$, in sequence. Figure (41) illustrates the effect of the triple interactions between the studied treatments.

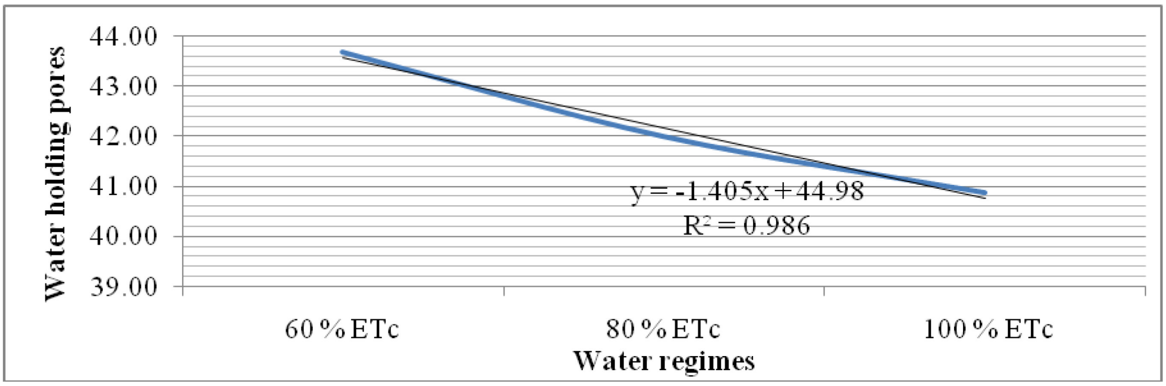


**Fig.(40): Effect of water regimes on water holding pores**

**Table (27): Effect of compost and mulch on water holding pores under different drip water regimes**

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 37.10 | 39.60 | **38.35** |
| | 12 ton/ha | 38.82 | 38.90 | **38.86** |
| | 24 ton/ha | 42.00 | 40.00 | **41.00** |
| | 36 ton/ha | 44.70 | 45.80 | **45.25** |
| | Mean | 40.66 | 41.08 | **40.87** |
| 80 % of $ET_c$ | Non-compost | 41.30 | 35.40 | **38.35** |
| | 12 ton/ha | 38.30 | 39.40 | **38.85** |
| | 24 ton/ha | 49.80 | 42.30 | **46.05** |
| | 36 ton/ha | 44.90 | 44.50 | **44.70** |
| | Mean | 43.58 | 40.40 | **41.99** |
| 60 % of $ET_c$ | Non-compost | 38.60 | 32.50 | **35.55** |
| | 12 ton/ha | 42.50 | 41.50 | **42.00** |
| | 24 ton/ha | 49.20 | 47.20 | **48.20** |
| | 36 ton/ha | 50.10 | 47.80 | **48.95** |
| | Mean | **45.10** | **42.25** | **43.68** |
| | Mean | **43.11** | **41.24** | |
| **Grand mean** | | | | **42.18** |

**Mean of compost**

| Compost | Water regime | | | Mean |
|---|---|---|---|---|
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| Non-compost | 38.35 | 38.35 | 35.55 | **37.42** |
| 12 ton/ha | 38.86 | 38.85 | 42.00 | **39.90** |
| 24 ton/ha | 41.00 | 46.05 | 48.20 | **45.08** |
| 36 ton/ha | 45.25 | 44.70 | 48.95 | **46.30** |
| Mean | **40.87** | **41.99** | **43.68** | **42.18** |

* = 4000 $m^3$/ha

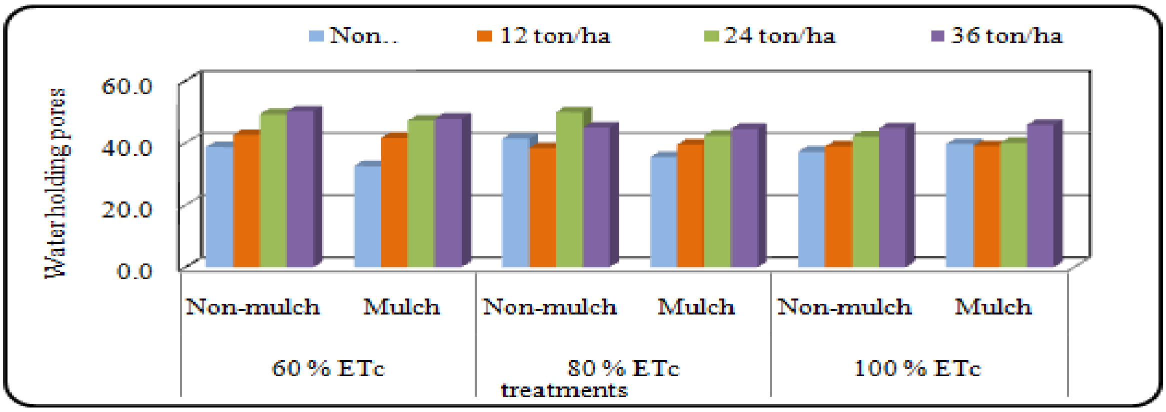


**Fig.(41): Effect of compost and mulch on water holding pores under different drip water regimes**

### *5.2.1.4.3. Effect of treatments on non-useful pores (pores < 0.19 µm in diameter) :-*

In respect of the effect of compost on pores < 0.19 µm in diameter, there was no clear effect of incorporating compost in the soil on its pores < 0.19 µm in diameter, compared to the soil that didn't receive compost but the highest value of the pores < 0.19 µm in diameter were obtained by the application rate of compost at 36 ton ha$^{-1}$ (table 28).

On the other hand, it could be noticed that mulching generally reduced the values of pores < 0.19 µm in diameter. Comparing the pores < 0.19 µm in diameter of the mulched soil to that of the non-mulched one, pores < 0.19 µm in diameter of the former was lower than that of the latter by 1.8 %.

Regarding the effect of water regimes on pores < 0.19 µm in diameter; data in hand showed that 60 % of $ET_c$ gave the highest value.

### *5.2.1.4.4. Effect of treatments on micro/ macro pores (<28.7/>28.7):-*

Incorporating compost in the soil obviously increased the amount of its micro/ macro pores, compared to the soil that didn't receive compost. The more amount of applied compost was, the higher ratio was micro/ macro pores. In other words, increments in micro/ macro pores of the soil treated with compost, compared to the soil that didn't receive compost were 13.1, 38.7 and 55.0 % for the application rates of compost 12, 24 and 36 ton ha$^{-1}$, respectively (fig. 42).

**Table (28): Effect of compost and mulch on non-useful pores under different drip water regimes**

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 27.30 | 25.10 | **26.20** |
| | 12 ton/ha | 22.60 | 21.50 | **22.05** |
| | 24 ton/ha | 22.70 | 21.90 | **22.30** |
| | 36 ton/ha | 25.15 | 22.90 | **24.03** |
| | Mean | **24.44** | **22.85** | **23.64** |
| 80 % of $ET_c$ | Non-compost | 20.20 | 23.30 | **21.75** |
| | 12 ton/ha | 25.70 | 23.70 | **24.70** |
| | 24 ton/ha | 22.60 | 24.00 | **23.30** |
| | 36 ton/ha | 23.30 | 25.10 | **24.20** |
| | Mean | **22.95** | **24.03** | **23.49** |
| 60 % of $ET_c$ | Non-compost | 24.30 | 23.70 | **24.00** |
| | 12 ton/ha | 27.50 | 25.70 | **26.60** |
| | 24 ton/ha | 24.50 | 23.90 | **24.20** |
| | 36 ton/ha | 26.00 | 25.60 | **25.80** |
| | Mean | **25.58** | **24.73** | **25.15** |
| | Mean | **24.32** | **23.87** | |
| **Grand mean** | | | | **24.09** |
| | | **Mean of compost** | | |
| **Compost** | Water regime | | | **Mean** |
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| **Non-compost** | 26.20 | 21.75 | 24.00 | **23.98** |
| **12 ton/ha** | 22.05 | 24.70 | 26.60 | **24.45** |
| **24 ton/ha** | 22.30 | 23.30 | 24.20 | **23.27** |
| **36 ton/ha** | 24.03 | 24.20 | 25.80 | **24.68** |
| **Mean** | **23.64** | **23.49** | **25.15** | **24.09** |

* = 4000 $m^3$/ha

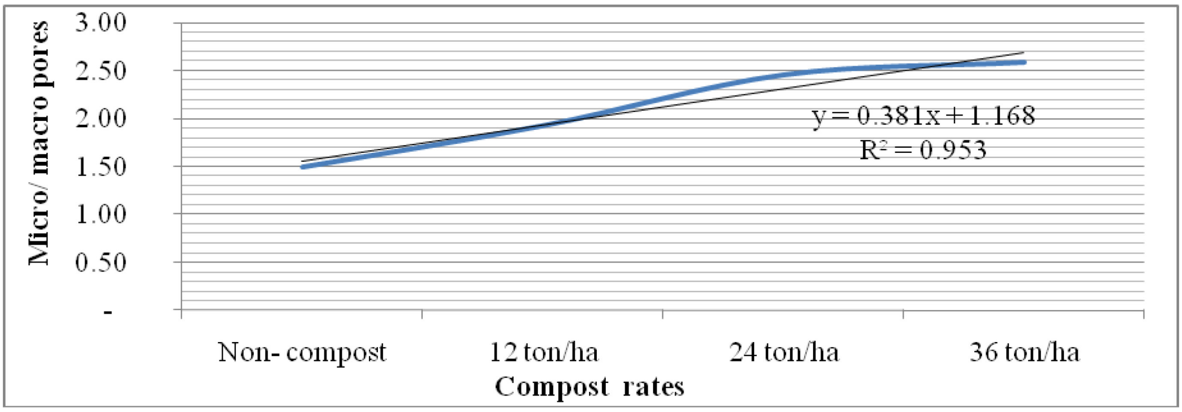


**Fig.(42): Effect of compost on micro/ macro pores**

In contrast, it can be observed that mulching generally decreased the values of micro/ macro pores. Comparing the mulched soil to the non-mulched one, micro/ macro pores ratio of the former was lower amount than that of the latter by 9.3 %.

About the effect of water regimes on micro/ macro pores (fig. 43), data in hand revealed that increasing applied water to the soil decreased its micro/ macro pores ratio. In detail, decrements in micro/ macro pores were 15.6 and 20.4 % that of the soil received 60 % of its $ET_c$ for the soils that received 80 % and 100 % of their $ET_c$, in sequence. Figure (44) illustrates the effect of the triple interactions between the studied treatments

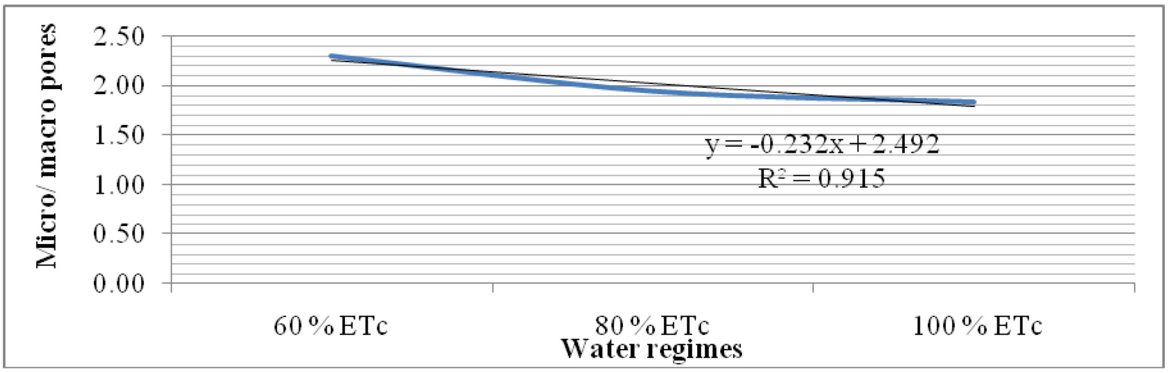


**Fig.(43): Effect of water regimes on micro/ macro pores**

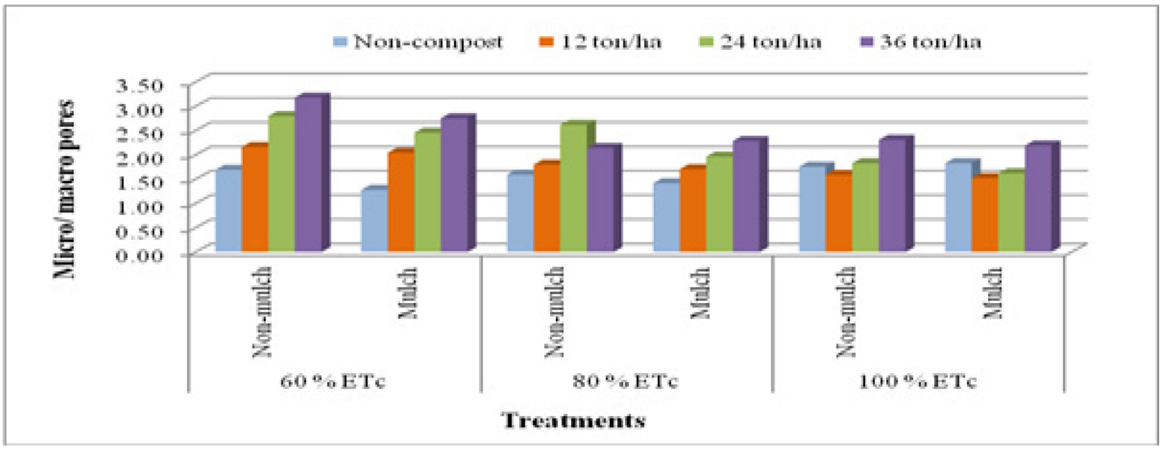


**Fig. (44): Effect of compost and mulch on micro/ macro pores under different drip water regimes**

### *5.2.2. Effect of treatments on water transmitting properties:-*

Alteration of water transmitting properties of sandy soil i.e. the rapid loss of water by either deep percolation or evaporation, is one the major objective of soil conditioning. Some water transmitting properties of the soil as influenced by soil mulching, applying compost and water regimes are presented in figures (45-51).

These properties include the infiltration rate of the dry soil (cm $h^{-1}$), the minimum hydraulic conductivity in $day^{-1}$ after percolation for three hours under a constant water head and mean diameter of soil pores (μm). Data in hand are shown the following:-

### *5.2.2.1. __Effect of treatments on infiltration rate :-__*

Incorporating compost in the soil decreased its infiltration rate compared to the soil which didn't receive compost. The more amount of applied compost was, the lower was infiltration rate. In other words, decrements in infiltration rate of the soil treated with compost, compared to that of the soil that didn't receive compost were 9.4, 25.08 and 37.1 % for the applying 12, 24 and 36 ton $ha^{-1}$ of compost, respectively (fig.45).

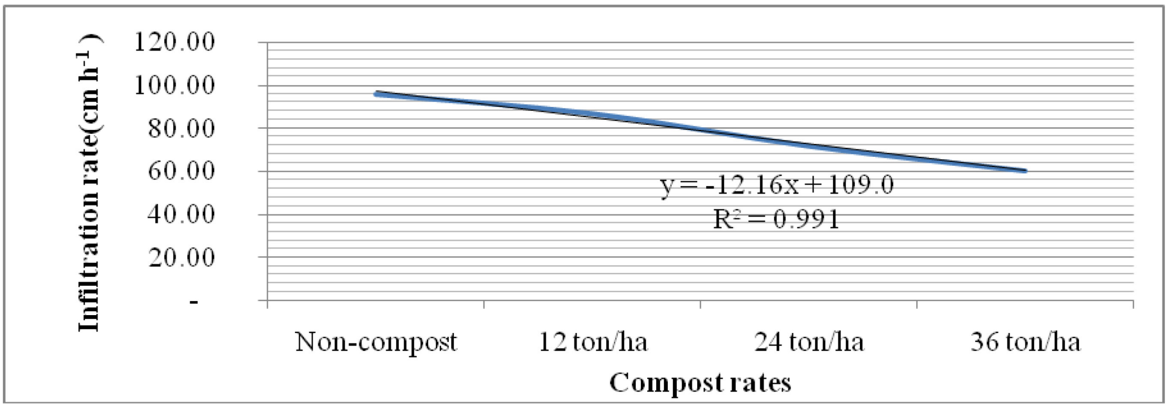


**Fig.(45): Effect of compost on infiltration rate**

Moreover, it is observed that soil mulching generally decreased the values of infiltration rate under all treatments of applying compost and water regimes. Comparing the infiltration rate of the mulched soil to that of the non-mulched one, infiltration rate of the former was lower than that of the latter about 4.2 %.

Referring to the effect of water regimes on infiltration rate, data in hand revealed that increasing applied water to the soil decreased its infiltration rate. In detail, values of infiltration rate of the soil were 99.6 and 89.74 % that of the soil received 60 % of its $ET_c$ for the soils that received 80 % and 100 % of their $ET_c$, in sequence. Effect of the triple interactions among the treatments on infiltration rate is shown in figure (46).

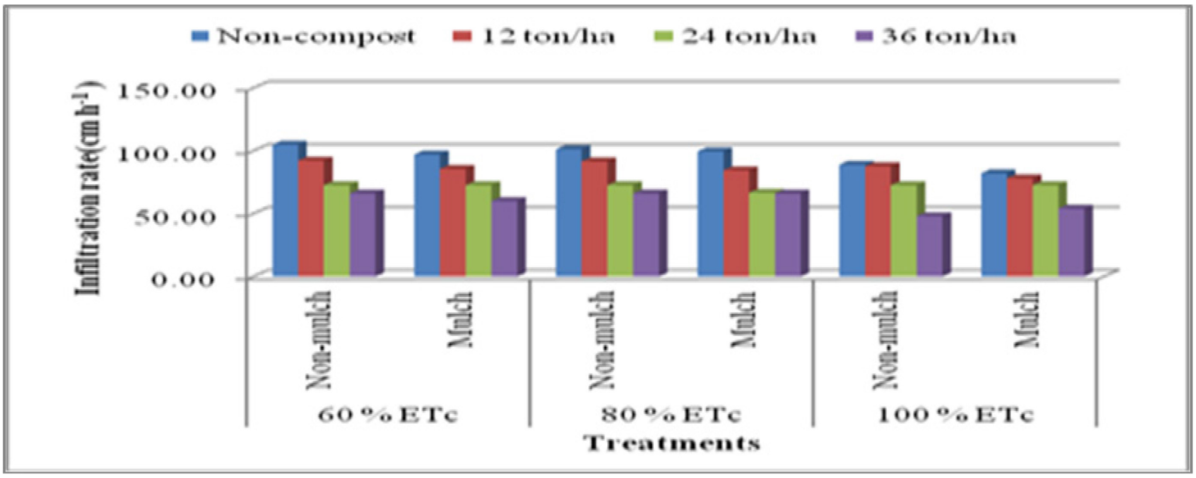


**Fig. (46): Effect of compost and mulch on infiltration rate under different drip water regimes**

### *5.2.2.2. Effect of treatments on hydraulic conductivity:*

Values of hydraulic conductivity affected by soil mulching, applying compost and water regimes are shown in figures (47-49). Incorporating compost in the soil decreased its hydraulic conductivity compared to the soil which didn't receive compost. The more the amount of applied compost was, the lower was the hydraulic conductivity. In other words, decrements in hydraulic conductivity of the soil treated with compost, compared to that of the soil didn't receive compost were 21.5, 37.7 and 46.6 % for applying 12, 24 and 36 ton ha$^{-1}$ of compost, respectively.

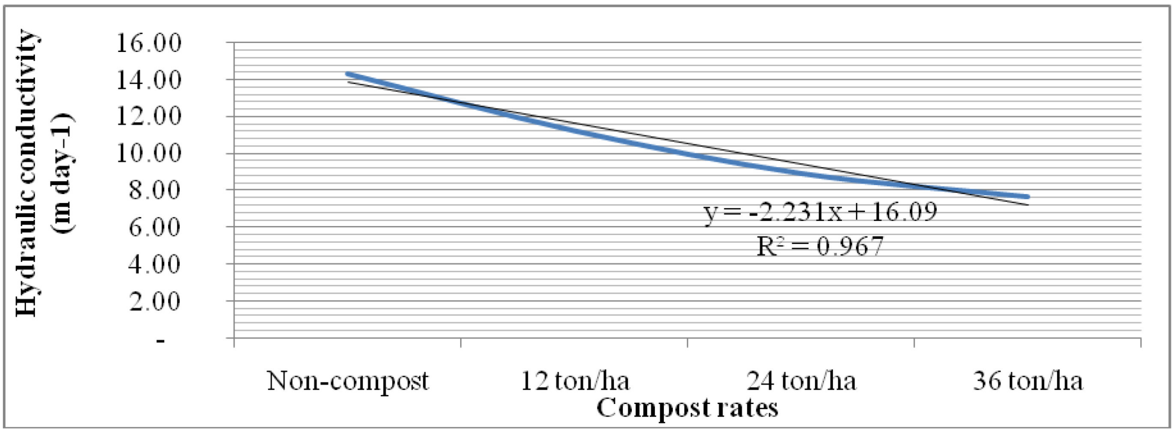


**Fig.(47): Effect of compost on hydraulic conductivity**

On the contrary, it could be observed that soil mulching generally increased the values of hydraulic conductivity under all treatments of applying compost and water regimes.

Comparing the hydraulic conductivity of the mulched soil to that of the non-mulched one, hydraulic conductivity of the former was lower than that of the latter by 2.6 %.

Concerning the effect of water regimes on hydraulic conductivity, available data reveal that in general, increasing applied water to the soil increased its hydraulic conductivity. The lowest value of hydraulic conductivity was obtained by 60 % of $ET_c$.

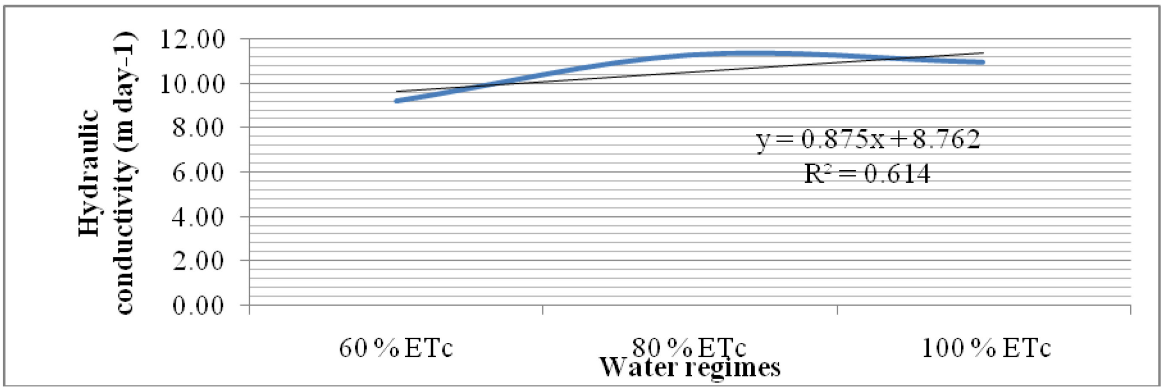


**Fig.(48): Effect of water regimes on hydraulic conductivity**

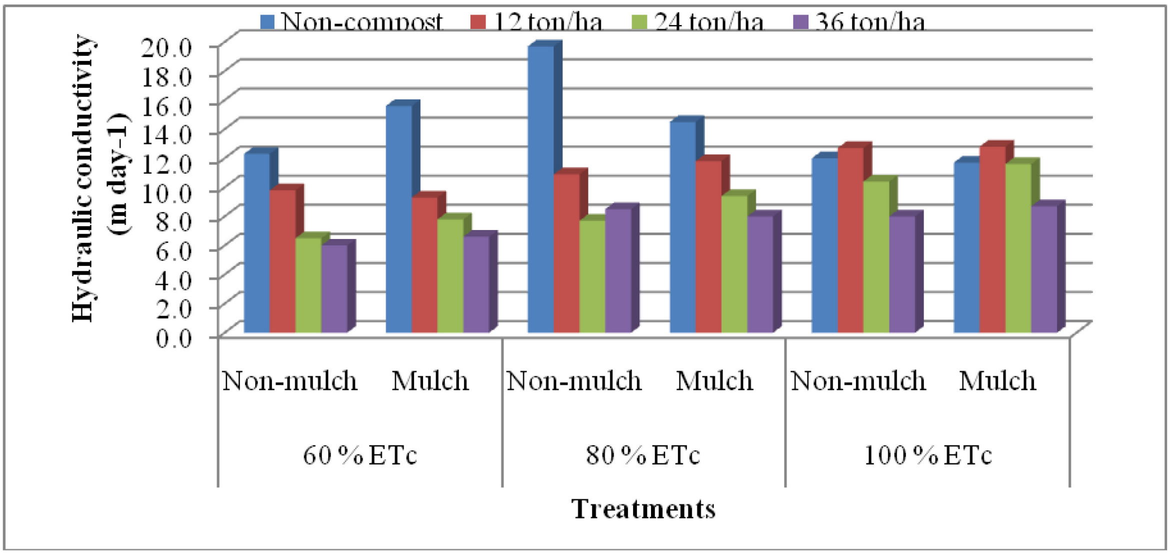


**Fig.(49): Effect of compost and mulch on hydraulic conductivity under different drip water regimes**

### *5.2.2.3. <u>Effect of treatments on mean diameter of soil pores (µm)</u>*

Incorporating compost in the soil reduced its mean diameter of soil pores compared to the soil that didn't receive compost (fig.50). Decrements in the mean diameter of soil pores of the soil treated with compost, compared to that of the soil that didn't receive compost were

7.7, 18.03 and 23.71 % for the application rates of compost 12, 24 and 36 ton $ha^{-1}$, respectively (table 29).

On the other hand, it could be noticed that soil mulching generally increased the values of mean diameter of soil pores under all treatments of applying compost and water regimes. Comparing mean diameter of soil pores of the mulched soil to that of the non-mulched one, mean diameter of soil pores of the former was higher than that of the latter by 4.11 %.

Concerning the effect of water regimes on the mean diameter of soil pores, increasing applied water enlarged its mean diameter of soil pores. In detail, increases in the mean diameter of soil pores were 7.0 and 10 % that of the soil received 60% of $ET_c$ for the soils that received 80 and 100% of their $ET_c$, in sequence (fig.51).

**Table (29): Effect of compost and mulch on mean diameter (µm) of soil under different water regimes**

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 21.4 | 21.1 | **21.25** |
| | 12 ton/ha | 22.0 | 22.1 | **22.05** |
| | 24 ton/ha | 19.9 | 21.0 | **20.45** |
| | 36 ton/ha | 17.5 | 18.2 | **17.85** |
| | **Mean** | **20.20** | **20.60** | **20.40** |
| 80 % of $ET_c$ | Non-compost | 22.0 | 23.5 | **22.75** |
| | 12 ton/ha | 20.4 | 21.2 | **20.80** |
| | 24 ton/ha | 17.1 | 18.9 | **18.00** |
| | 36 ton/ha | 18.0 | 17.5 | **17.75** |
| | **Mean** | **19.38** | **20.28** | **19.83** |
| 60 % of $ET_c$ | Non-compost | 21.7 | 24.4 | **23.05** |
| | 12 ton/ha | 19.3 | 18.8 | **19.05** |
| | 24 ton/ha | 15.8 | 17.2 | **16.50** |
| | 36 ton/ha | 15.2 | 15.9 | **15.55** |
| | **Mean** | **18.00** | **19.08** | **18.54** |
| | **Mean** | **19.19** | **19.98** | |
| **Grand mean** | | | | **19.59** |

**Mean of compost**

| Compost | Water regime | | | Mean |
|---|---|---|---|---|
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| Non-compost | 21.25 | 22.75 | 23.05 | **22.35** |
| 12 ton/ha | 22.05 | 20.80 | 19.05 | **20.63** |
| 24 ton/ha | 20.45 | 18.00 | 16.50 | **18.32** |
| 36 ton/ha | 17.85 | 17.75 | 15.55 | **17.05** |
| **Mean** | **20.40** | **19.83** | **18.54** | **19.59** |

* = 4000 m³/ha

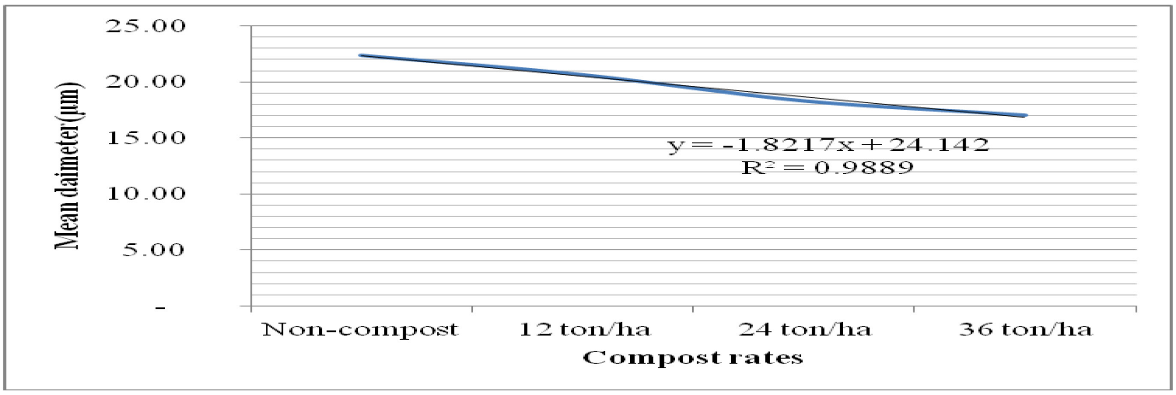


**Fig.(50): Effect of compost on mean diameter of soil pores**

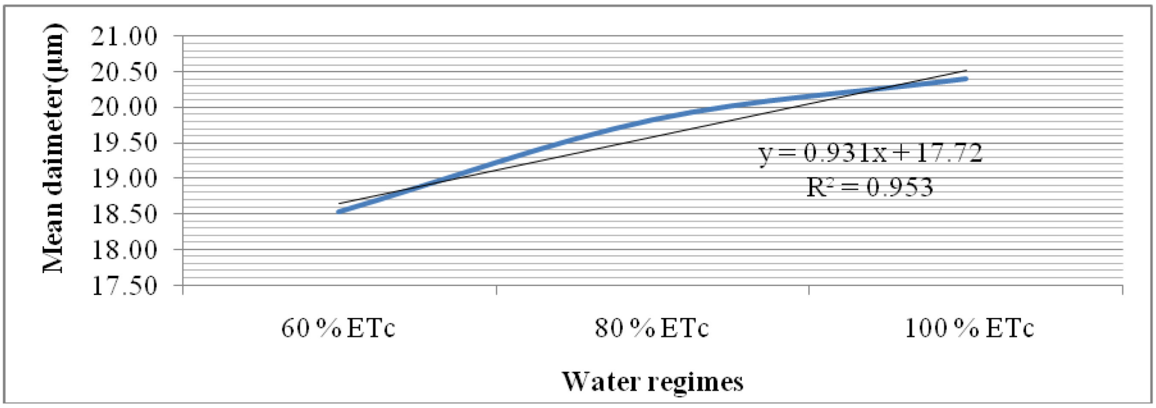


**Fig.(51): Effect of water regimes on mean diameter of soil pores**

### *5.2.3. Effect of treatments on moisture retention in the soil*

In the Western Desert, there are many suggested area for agricultural expansion. Unfortunately, these areas are sandy having poor physical properties especially low water retention. Therefore, using soil conditioners such as compost and soil mulching are of vital importance to solve a number of problems.

Retained moisture in the soil under different suctions influenced by soil mulching, applying compost and water regimes are shown in tables (30-33) and illustrated figure (52). Data in hand refer to the increase in percentages of retained moisture at all suctions under study as shown the following:-

**5.2.3.1.** ***At saturation*** i.e. at PF = 0, the total water holding capacity (WHC) of the soil

Incorporating compost in the soil amplified its total holding capacity of the soil. Increments in total holding capacity of the soil treated with compost, compared to that of the soil didn't receive compost were 34.30, 61.14 and 71.27 % for applying 12, 24 and 36 ton $ha^{-1}$ of compost, respectively (table 30).

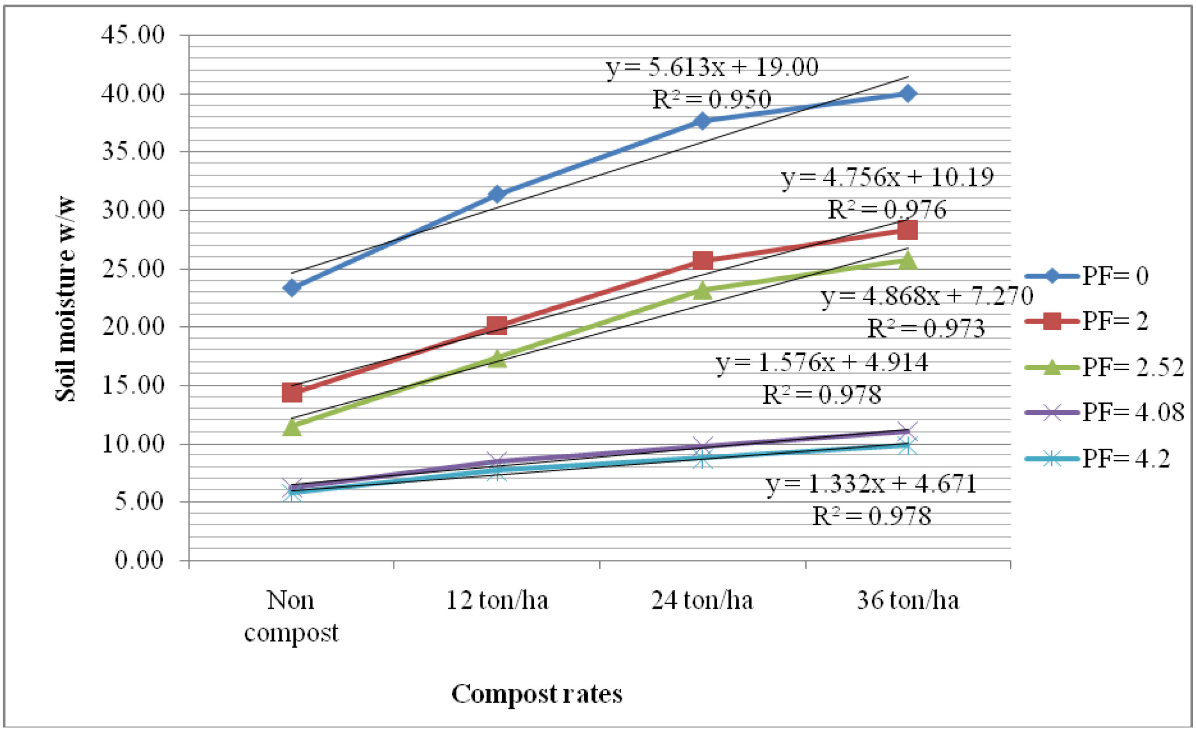


**Fig. (52): Effect of compost rates on soil moisture characteristics**

Concerning the effect of water regimes on the total holding capacity of the soil, data in hand declare that increasing applied water to the soil increased its total holding capacity. In details, increases of total holding capacity of the soil were 1.78 and 2.73 % that of the soil received 60 % of its $ET_c$ for the soils that received 80 % and 100 % of their $ET_c$, in sequence.

**5.2.3.2.** ***<u>At Field capacity (FC)</u>*** i.e. at PF = 2.0, values of retained moisture showed increments of relation to that of the total

Incorporating compost in the soil increased its field capacity. The increments in field capacity of the soil treated with compost, compared to that of the soil didn't receive compost were 40.15, 79.05 and 97.76 % for the application rates of compost 12, 24 and 36 ton $ha^{-1}$, respectively (table 31).

Additionally, it can be detected that soil mulching generally increased the values of field capacity under all treatments of applying compost and water regimes. Comparing the field capacity of the mulched soil to that of the non-mulched one, field capacity of the former was higher than that of the latter by 1.2 %.

In contrast, data in hand reveal that increasing applied water to the soil insignificantly decreased its field capacity. In detail, values of field capacity of the soil were 96.8 and 96.07 % that of the soil received 60 % of $ET_c$ for the soils that received 80 and 100 % of $ET_c$, in sequence.

***5.2.3.3. <u>At wilting percentages (WP)</u>:***

Applying compost in the soil increased its wilting percentages, compared to the soil that didn't receive compost. The increments in wilting percentages of the soil treated with compost, compared to that of the soil didn't receive compost, were 33.0, 51.7 and 70.8 % by applying 12, 24 and 36 ton $ha^{-1}$ of compost, respectively (table 32).

In respect of the effect of soil mulching on wilting percentages**,** it is noticed that soil mulching generally increased the values of wilting percentages under all treatments of applying compost and water regimes. Comparing the wilting percentages of the mulched soil to that of the non-mulched one, wilting percentages of the former was higher than that of the latter by 3.5 %.

As regards the effect of water regimes on wilting percentages; there was no trend, 60 % of $ET_c$ attained the highest value though.

***5.2.3.4. <u>Available water (w/w):-</u>***

Data in table (33) showed that incorporating compost in the soil obviously increased available water compared to the soil that didn't receive compost. Increments in available water of the soil treated with compost were 45.1, 97.6 and 160.2 % for applying 12, 24 and 36 ton $ha^{-1}$ of compost, respectively.

Concerning the effect of soil mulching on available water, there was no trend for an effect of mulching the soil on available water under all treatments of applying compost and water regimes. It could be noticed that in general, comparing the available water of the mulched soil to that of the non-mulched one, available water of the former was lower amount than that of the latter by 1.0 % only. On the other hand, data reveal that increasing applied water to the soil slightly decreased available water. In details, values of available water were 97.6 and 94.8 % that of the soil received 60 % of its $ET_c$ for the soils that received 80 % and 100 % of their $ET_c$, in sequence.

Obtained results could be explained that increasing the smaller pores having the diameter of 28.7 – 0.19 µm (table 36) in the expense of larger ones i.e. drainable pores having the diameter of > 28.7 µm.

As previously mentioned, the increase in amount of water storage pores is vital to insure water retention in sandy soil under dry forming conditions. It is well known that increasing available moisture for plants elongates irrigation frequencies and in turn decreases the quantities of irrigation water needed and costs of irrigation process.

**Table (30): Effect of compost and mulch on saturation percentage under different water regimes**

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 23.24 | 23.50 | **23.37** |
| | 12 ton/ha | 29.38 | 31.95 | **30.66** |
| | 24 ton/ha | 37.74 | 39.91 | **38.82** |
| | 36 ton/ha | 40.39 | 41.44 | **40.92** |
| | Mean | **32.69** | **34.20** | **33.44** |
| 80 % of $ET_c$ | Non-compost | 23.24 | 23.80 | **23.52** |
| | 12 ton/ha | 31.01 | 32.69 | **31.85** |
| | 24 ton/ha | 35.63 | 37.74 | **36.69** |
| | 36 ton/ha | 40.09 | 40.82 | **40.45** |
| | Mean | **32.49** | **33.76** | **33.13** |
| 60 % of $ET_c$ | Non-compost | 22.69 | 23.43 | **23.06** |
| | 12 ton/ha | 30.38 | 32.54 | **31.46** |
| | 24 ton/ha | 36.34 | 38.13 | **37.24** |
| | 36 ton/ha | 37.74 | 39.18 | **38.46** |
| | Mean | **31.79** | **33.32** | **32.55** |
| | Mean | **32.32** | **33.76** | |
| Grand mean | | | | **33.04** |

**Mean of compost**

| Compost | Water regime | | | Mean |
|---|---|---|---|---|
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| Non-compost | 23.37 | 23.52 | 23.06 | **23.32** |
| 12 ton/ha | 30.66 | 31.85 | 31.46 | **31.32** |
| 24 ton/ha | 38.82 | 36.69 | 37.24 | **37.58** |
| 36 ton/ha | 40.92 | 40.45 | 38.46 | **39.94** |
| Mean | **33.44** | **33.13** | **32.55** | **33.04** |

* = 4000 m³/ha

**Table (31): Effect of compost and mulch on field capacity (0.1 bar %w/w) under different water regimes**

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 14.97 | 15.21 | **15.09** |
| | 12 ton/ha | 18.04 | 19.31 | **18.68** |
| | 24 ton/ha | 24.44 | 24.72 | **24.58** |
| | 36 ton/ha | 28.20 | 28.48 | **28.34** |
| | Mean | **21.41** | **21.93** | **21.67** |
| 80 % of $ET_c$ | Non-compost | 14.28 | 14.00 | **14.14** |
| | 12 ton/ha | 20.00 | 20.64 | **20.32** |
| | 24 ton/ha | 25.80 | 25.00 | **25.40** |
| | 36 ton/ha | 27.34 | 28.43 | **27.89** |
| | Mean | **21.86** | **22.02** | **21.94** |
| 60 % of $ET_c$ | Non-compost | 14.28 | 13.16 | **13.72** |
| | 12 ton/ha | 20.58 | 21.87 | **21.23** |
| | 24 ton/ha | 26.77 | 27.11 | **26.94** |
| | 36 ton/ha | 28.7 | 28.75 | **28.73** |
| | Mean | **22.58** | **22.72** | **22.65** |
| | Mean | **21.95** | **22.22** | |
| Grand mean | | | | **22.09** |

**Mean of compost**

| Compost | Water regime | | | Mean |
|---|---|---|---|---|
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| Non-compost | 15.09 | 14.14 | 13.72 | **14.32** |
| 12 ton/ha | 18.68 | 20.32 | 21.23 | **20.07** |
| 24 ton/ha | 24.58 | 25.40 | 26.94 | **25.64** |
| 36 ton/ha | 28.34 | 27.89 | 28.73 | **28.32** |
| Mean | **21.67** | **21.94** | **22.65** | **22.09** |

* = 4000 $m^3$/ha

**Table (32): Effect of compost and mulch on wilting percentage (-15 bar) % w/w under different water regimes**

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 6.34 | 6.91 | **6.63** |
| | 12 ton/ha | 6.64 | 6.89 | **6.77** |
| | 24 ton/ha | 8.57 | 8.77 | **8.67** |
| | 36 ton/ha | 10.16 | 9.50 | **9.83** |
| | Mean | **7.93** | **8.02** | **7.97** |
| 80 % of $ET_c$ | Non-compost | 4.69 | 5.56 | **5.13** |
| | 12 ton/ha | 7.98 | 7.75 | **7.87** |
| | 24 ton/ha | 8.07 | 9.06 | **8.57** |
| | 36 ton/ha | 9.34 | 10.21 | **9.78** |
| | Mean | **7.52** | **8.15** | **7.83** |
| 60 % of $ET_c$ | Non-compost | 5.52 | 5.56 | **5.54** |
| | 12 ton/ha | 8.34 | 8.36 | **8.35** |
| | 24 ton/ha | 8.89 | 9.10 | **9.00** |
| | 36 ton/ha | 9.81 | 10.04 | **9.93** |
| | Mean | **8.14** | **8.27** | **8.20** |
| | Mean | **7.86** | **8.14** | |
| Grand mean | | | | **8.00** |

**Mean of compost**

| Compost | Water regime | | | Mean |
|---|---|---|---|---|
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| Non-compost | 6.63 | 5.13 | 5.54 | **5.76** |
| 12 ton/ha | 6.77 | 7.87 | 8.35 | **7.66** |
| 24 ton/ha | 8.67 | 8.57 | 9.00 | **8.74** |
| 36 ton/ha | 9.83 | 9.78 | 9.93 | **9.84** |
| Mean | **7.97** | **7.83** | **8.20** | **8.00** |

* = 4000 $m^3$/ha

Table (33): Effect of compost and mulch on available water in the soil under different water regimes

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 8.63 | 8.30 | **8.47** |
| | 12 ton/ha | 11.40 | 12.42 | **11.91** |
| | 24 ton/ha | 15.87 | 15.95 | **15.91** |
| | 36 ton/ha | 18.04 | 18.98 | **18.51** |
| | Mean | **13.49** | **13.91** | **13.70** |
| 80 % of $ET_c$ | Non-compost | 9.59 | 8.44 | **9.02** |
| | 12 ton/ha | 12.02 | 12.89 | **12.46** |
| | 24 ton/ha | 17.73 | 15.94 | **16.84** |
| | 36 ton/ha | 18.00 | 18.22 | **18.11** |
| | Mean | **14.34** | **13.87** | **14.10** |
| 60 % of $ET_c$ | Non-compost | 8.76 | 7.60 | **8.18** |
| | 12 ton/ha | 12.24 | 13.51 | **12.88** |
| | 24 ton/ha | 17.88 | 18.01 | **17.95** |
| | 36 ton/ha | 18.89 | 18.71 | **18.80** |
| | Mean | **14.44** | **14.46** | **14.45** |
| | Mean | **14.09** | **14.08** | |
| Grand mean | | | | **14.08** |

Mean of compost

| Compost | Water regime | | | Mean |
|---|---|---|---|---|
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| Non-compost | 8.47 | 9.02 | 8.18 | **8.55** |
| 12 ton/ha | 11.91 | 12.46 | 12.88 | **12.41** |
| 24 ton/ha | 15.91 | 16.84 | 17.95 | **16.90** |
| 36 ton/ha | 18.51 | 18.11 | 18.80 | **18.47** |
| Mean | **13.70** | **14.10** | **14.45** | **14.08** |

* = 4000 $m^3$/ha

### *5.3. Plant water relationships:-*

#### *5.3.1. Water consumption for potato plants:-*

Figures (53-58) described the amounts of consumed for potato from the three layers of root zone i.e. 0-20, 20-40, 40-60 cm. Using drip irrigation in combination with compost treatment, potato plants consumed water more than other from the layer of 0.00-0.20 m where compost was incorporated in this soil layer. Furthermore, water consumption for potato increased in mulched soil compared to that in non-mulched one.

With respect to the average amounts of water consumed by drip irrigated potato plants at every growth stage as shown in table (34), it's clear that these amounts increased with increasing irrigation water levels and compost rates in mulched soil. The highest amount of consumed water for potato was 3567.8 $m^3$/ha, while the lowest one was 1716.2 $m^3$/ha. Obtained data indicate that the water consumption for potato plant started with a small amount because the tuber seedling needs are less at the initial growth stage. Therefore, soil moisture losses occurred mainly by evaporation from the soil surface. Subsequently the water consumption gradually increased until the peak amount in the middle of season then decreased until the tuber maturity. Soil moisture depletion in these growing stages is mostly due to the evapotranspiration by plants.

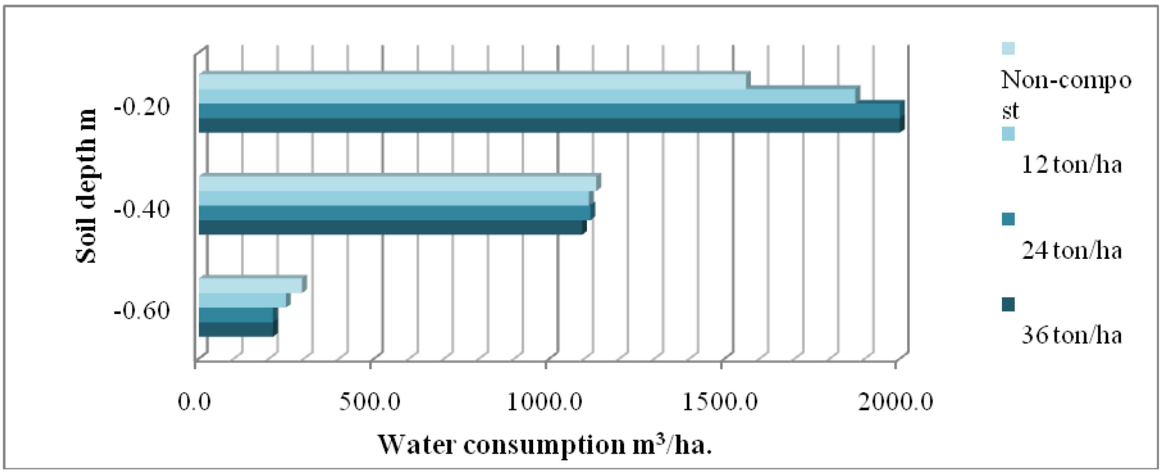


**Fig.(53): Effect of compost on water consumption $m^3$/ha for drip irrigated potato by 100 % of $ET_c$ in non- mulched soil**

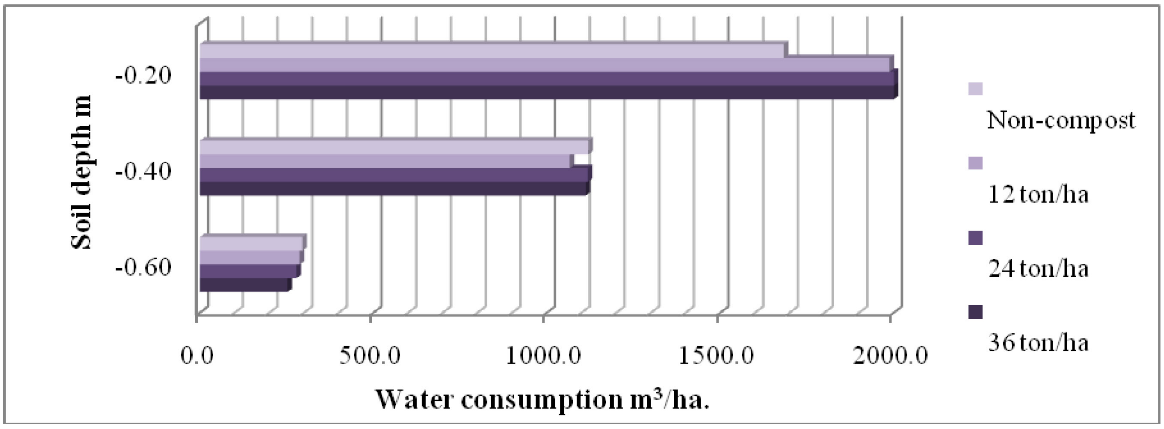


**Fig.(54): Effect of compost on water consumption m$^3$/ha for drip irrigated potato by 100 % of ET$_c$ in mulched soil**

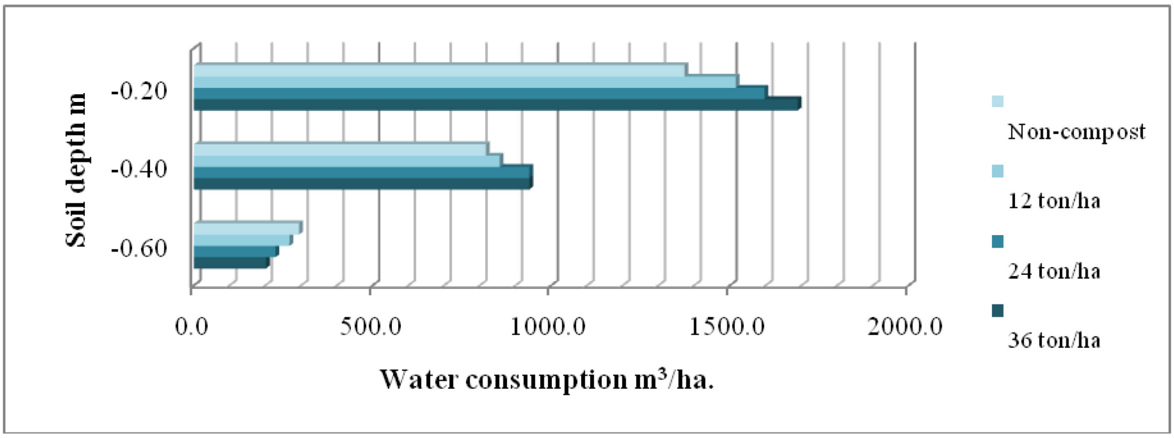


**Fig.(55): Effect of compost on water consumption m$^3$/ha for drip irrigated potato by 80 % of ET$_c$ in non- mulched soil**

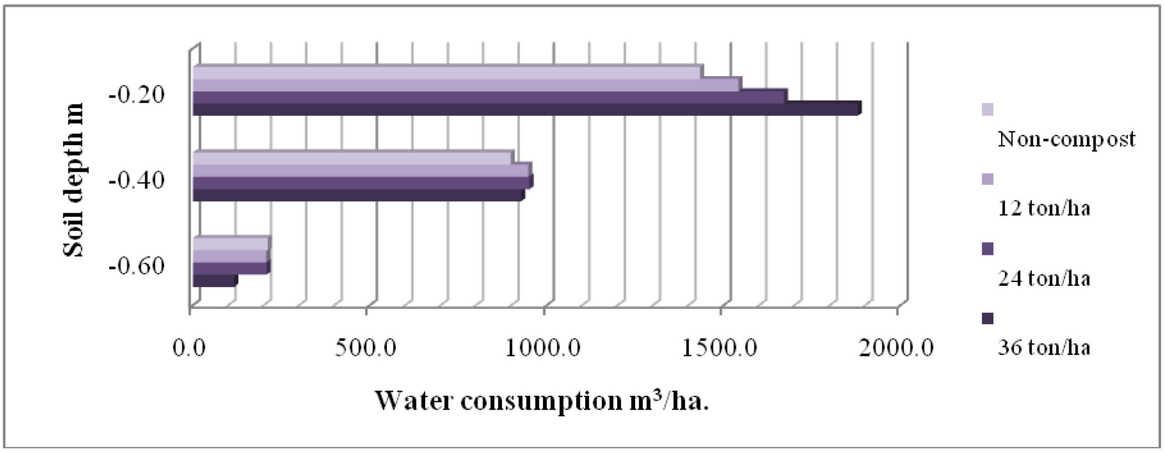


**Fig.(56): Effect of compost on water consumption m$^3$/ha for drip irrigated potato by 80 % of ET$_c$ in mulched soil**

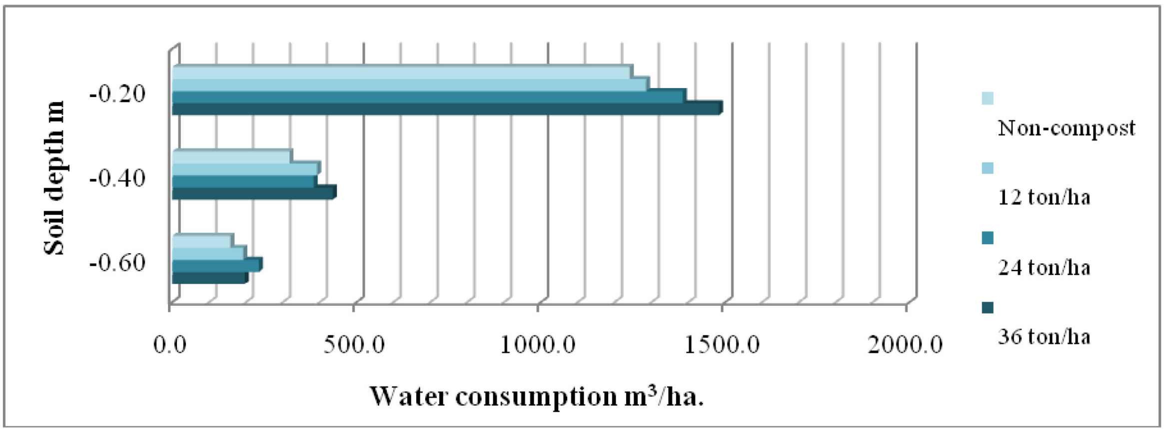


**Fig.(57): Effect of compost on water consumption $m^3$/ha for drip irrigated potato by 60 % of $ET_c$ in non- mulched soil**

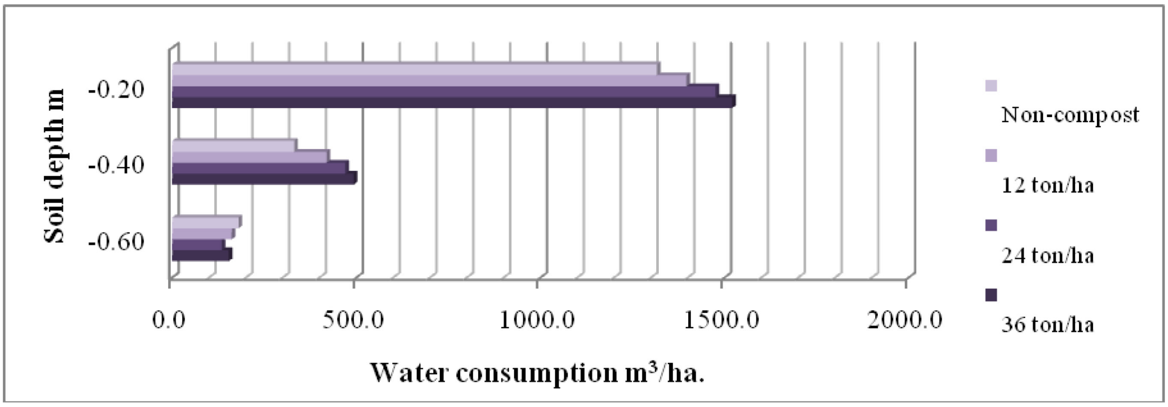


**Fig.(58): Effect of compost on water consumption $m^3$/ha for drip irrigated potato by 60 % of $ET_c$ in mulched soil**

### *5.3.2. Effect of treatments on total water consumption of potato ($m^3 ha^{-1}$) :-*

Data shown in tables (34) revealed that obviously applying compost had great effect on total water consumption for potato. In other words, applying compost at the rate of 12, 24 and 36 ton $ha^{-1}$ respectively increased total water consumption of potato plants by 75 %, 137.8 %, and 167.3 % over total water consumption of the potato plants that hadn't received compost.

Moreover, soil mulching had a slight influence on the total water consumption for potato under all treatments of applying compost and water regimes. Comparing the total water consumption of plants in the mulched soil to that in the non-mulched one, the total water consumption for the former was higher than that of the latter by 4.5 %.

Concerning the effect of water regimes, it's clear that total water consumption for potato increased with increasing water irrigation level. The increments were 37.8 % and 69.7

% for 80 and 100 % of $ET_c$ compared to that of the 60 % of $ET_c$ water regime. Noteworthy that increasing the total water consumption by increasing water irrigation level caused a negative effect on potato production.

**Table (34): Effect of treatment on potato water consumption during growth stages (winter season 2005/2006)**

| Water regimes | Mulch | Compost | Initial | Development | Mid-season | Late-season | Maturity | Total water consumption |
|---|---|---|---|---|---|---|---|---|
| Growth stage date | | | 26.10.05-15.11.05 | 16.11.05-15.12.05 | 16.12.05-24.01.06 | 25.01.06-14.02.06 | 15.02.06-26.02.06 | **26.10.05 - 26.02.06** |
| **W1** | **M0** | **C0** | 222.5 | 770.8 | 1300.9 | 521.8 | 174.2 | **2990.3** |
| **W1** | **M0** | **C1** | 251.2 | 841.9 | 1367.5 | 564.8 | 209.3 | **3234.7** |
| **W1** | **M0** | **C2** | 263.4 | 853.5 | 1526.4 | 583.2 | 232.8 | **3459.3** |
| **W1** | **M0** | **C3** | 267.9 | 858.4 | 1555.6 | 587 | 238.8 | **3507.8** |
| **W1** | **M1** | **C0** | 232.8 | 799.4 | 1344.7 | 535 | 185.8 | **3097.7** |
| **W1** | **M1** | **C1** | 260.9 | 844.4 | 1444.9 | 575.8 | 214.6 | **3340.7** |
| **W1** | **M1** | **C2** | 273.5 | 865.8 | 1574.7 | 593.1 | 238 | **3545.3** |
| **W1** | **M1** | **C3** | 268.1 | 855.3 | 1596.1 | 609.2 | 239.1 | **3567.8** |
| **W2** | **M0** | **C0** | 158.9 | 616.3 | 1160.3 | 411.1 | 138.1 | **2484.8** |
| **W2** | **M0** | **C1** | 167 | 649.9 | 1249.7 | 412.7 | 160.3 | **2639.6** |
| **W2** | **M0** | **C2** | 178.4 | 670.1 | 1285 | 454.1 | 176 | **2763.6** |
| **W2** | **M0** | **C3** | 180.5 | 698.3 | 1305.6 | 457.8 | 188.5 | **2830.8** |
| **W2** | **M1** | **C0** | 162.8 | 624.7 | 1198.8 | 423.9 | 133.2 | **2543.4** |
| **W2** | **M1** | **C1** | 173.4 | 649.5 | 1278.5 | 431.1 | 165.1 | **2697.5** |
| **W2** | **M1** | **C2** | 179.6 | 688 | 1329.5 | 457.3 | 175.7 | **2830.1** |
| **W2** | **M1** | **C3** | 192.4 | 690 | 1355.8 | 496.4 | 189.6 | **2924.3** |
| **W3** | **M0** | **C0** | 121.9 | 418.5 | 815.8 | 273 | 86.9 | **1716.2** |
| **W3** | **M0** | **C1** | 123 | 438.6 | 905.8 | 310.9 | 92.1 | **1870.4** |
| **W3** | **M0** | **C2** | 127.6 | 496.6 | 945.9 | 334.9 | 98 | **2003** |
| **W3** | **M0** | **C3** | 139.2 | 509.5 | 1017.6 | 340.8 | 108.1 | **2115.1** |
| **W3** | **M1** | **C0** | 124.4 | 446.8 | 871.3 | 293.2 | 92.6 | **1828.3** |
| **W3** | **M1** | **C1** | 131 | 463.1 | 952.7 | 334.3 | 96.6 | **1977.7** |
| **W3** | **M1** | **C2** | 137.4 | 469.6 | 1018.1 | 351.2 | 104 | **2080.3** |
| **W3** | **M1** | **C3** | 141.6 | 510.6 | 1045.9 | 351.4 | 118 | **2167.5** |

Where: W1, W2 and W3 = water regime at 100, 80 and 60 % of $ET_c$ respectively.

M0, M1 = without mulch, with mulch (24 ton/ha), respectively.

C0, C1, C2 and C3 = Compost at 0, 12, 24 and 36 ton/ha, respectively.

### *5.3.3. Crop coefficients ($K_c$) for potato :-*

Crop coefficients for drip-irrigated potato are not known under the Western Desert conditions in Egypt, although Egypt was classed as the world's top potato exporters - in 2004. Efficient management of irrigation systems requires reasonable estimation of water consumption between irrigations. The results revealed crop coefficient varying during potato growth stages, mid-season crop coefficients for potato ranged from 0.72 to 0.96.

Obtained data in tables (35) and figures (59-61) illustrated the general effect of compost, soil mulching and water regimes, and the triple interactions between them on crop coefficient for potato.

**Table (35): Effect of treatment on potato crop coefficient ($K_c$) during growth stages**

| Water regimes | Mulch | Compost | Initial | Development | Mid-season | Late-season | Maturity | Seasonal $K_c$ |
|---|---|---|---|---|---|---|---|---|
| **W1** | **M0** | **C0** | 0.70 | 0.83 | 0.72 | 0.77 | 0.63 | 0.75 |
| **W1** | **M0** | **C1** | 0.79 | 0.91 | 0.75 | 0.84 | 0.75 | 0.81 |
| **W1** | **M0** | **C2** | 0.83 | 0.92 | 0.84 | 0.86 | 0.84 | 0.86 |
| **W1** | **M0** | **C3** | 0.84 | 0.92 | 0.86 | 0.87 | 0.86 | 0.87 |
| **W1** | **M1** | **C0** | 0.73 | 0.86 | 0.74 | 0.79 | 0.67 | 0.77 |
| **W1** | **M1** | **C1** | 0.82 | 0.91 | 0.80 | 0.85 | 0.77 | 0.83 |
| **W1** | **M1** | **C2** | 0.86 | 0.93 | 0.87 | 0.88 | 0.86 | 0.88 |
| **W1** | **M1** | **C3** | 0.84 | 0.92 | 0.88 | 0.90 | 0.86 | 0.89 |
| **W2** | **M0** | **C0** | 0.62 | 0.83 | 0.80 | 0.76 | 0.62 | 0.77 |
| **W2** | **M0** | **C1** | 0.65 | 0.88 | 0.86 | 0.76 | 0.72 | 0.82 |
| **W2** | **M0** | **C2** | 0.70 | 0.91 | 0.89 | 0.84 | 0.79 | 0.86 |
| **W2** | **M0** | **C3** | 0.71 | 0.94 | 0.90 | 0.85 | 0.85 | 0.88 |
| **W2** | **M1** | **C0** | 0.64 | 0.84 | 0.83 | 0.79 | 0.60 | 0.79 |
| **W2** | **M1** | **C1** | 0.68 | 0.88 | 0.88 | 0.80 | 0.74 | 0.84 |
| **W2** | **M1** | **C2** | 0.70 | 0.93 | 0.92 | 0.85 | 0.79 | 0.88 |
| **W2** | **M1** | **C3** | 0.75 | 0.93 | 0.94 | 0.92 | 0.85 | 0.91 |
| **W3** | **M0** | **C0** | 0.64 | 0.75 | 0.75 | 0.67 | 0.52 | 0.71 |
| **W3** | **M0** | **C1** | 0.64 | 0.79 | 0.83 | 0.77 | 0.55 | 0.78 |
| **W3** | **M0** | **C2** | 0.67 | 0.89 | 0.87 | 0.83 | 0.59 | 0.83 |
| **W3** | **M0** | **C3** | 0.73 | 0.91 | 0.94 | 0.84 | 0.65 | 0.88 |
| **W3** | **M1** | **C0** | 0.65 | 0.80 | 0.80 | 0.72 | 0.55 | 0.76 |
| **W3** | **M1** | **C1** | 0.69 | 0.83 | 0.88 | 0.82 | 0.58 | 0.82 |
| **W3** | **M1** | **C2** | 0.72 | 0.84 | 0.94 | 0.87 | 0.62 | 0.86 |
| **W3** | **M1** | **C3** | 0.74 | 0.92 | 0.96 | 0.87 | 0.71 | 0.90 |

Where: W1, W2 and W3 = water regime at 100, 80 and 60 % of $ET_c$ respectively.

M0, M1 = without mulch, with mulch (24 ton/ha), respectively.

C0, C1, C2 and C3 = Compost at 0, 12, 24 and 36 ton/ha, respectively.

#### *5.3.3.1. <u>General effect of the individual factors on crop coefficient :</u>*

With reference to the effect of compost rates, incorporating compost in the soil clearly increased crop coefficient (fig. 59) compared to the soil that didn't receive compost. Increments in crop coefficient of the soil treated with compost, compared to that of the soil didn't receive compost were 8.0, 13.1 and 17.1 % for the applying 12, 24 and 36 ton $ha^{-1}$of compost, respectively.

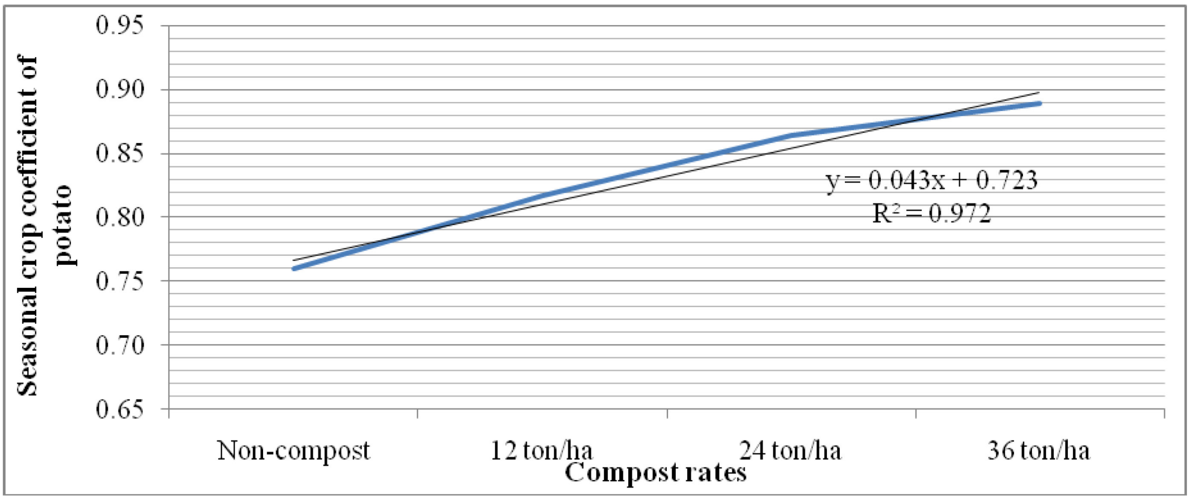


**Fig. (59): Effect of compost rates on seasonal crop coefficient ($K_c$)**

As regards the effect of mulching on crop coefficient, it could be observed that mulching generally increases the values of $K_c$ under all treatments of applying compost and water regimes. Comparing $K_c$ in the mulched soil to that of the non-mulched one, $K_c$ in the former was higher than that in the latter by 3.6 %.

Concerning the effect of water regimes on crop coefficient, data in hand declared that when using irrigation treatments alone, 80 % of $ET_c$ gave the best water regime. In details, the increasing applied water from 60 to 80 % of $ET_c$ increased $K_c$ then decreased with increasing applied water by 100 % of $ET_c$. Increases in $K_c$ were 3.6 and 1.2 % that of the soil received 60 % of its $ET_c$ for the soils that received 80 % and 100 % of their $ET_c$, in sequence.

#### *5.3.3.2. <u>Effect of the triple interactions among water regime, mulch and compost on crop coefficient :</u>*

There were noticeable influences of the triple interaction among water regimes, mulch and compost rates on crop coefficient. In other words, the decrement in applied water with increasing applied compost rates increased crop coefficient in mulched compared to non mulched soils. The maximum crop coefficient (0.91) was obtained by the combination between 80 % its water regime + mulching the soil + applying compost rate of 36 ton $ha^{-1}$ but the best value (0.86) achieved by the combination of (60 % of $ET_c$ water regime + mulching the soil + applying compost rate at 24 ton $ha^{-1}$) which attained the best tuber yield and net profit. On the other hand, the minimum crop coefficient (0.71) was recorded by the combination of (60 % of $ET_c$ water regime + non-mulching the soil + with no applying compost).

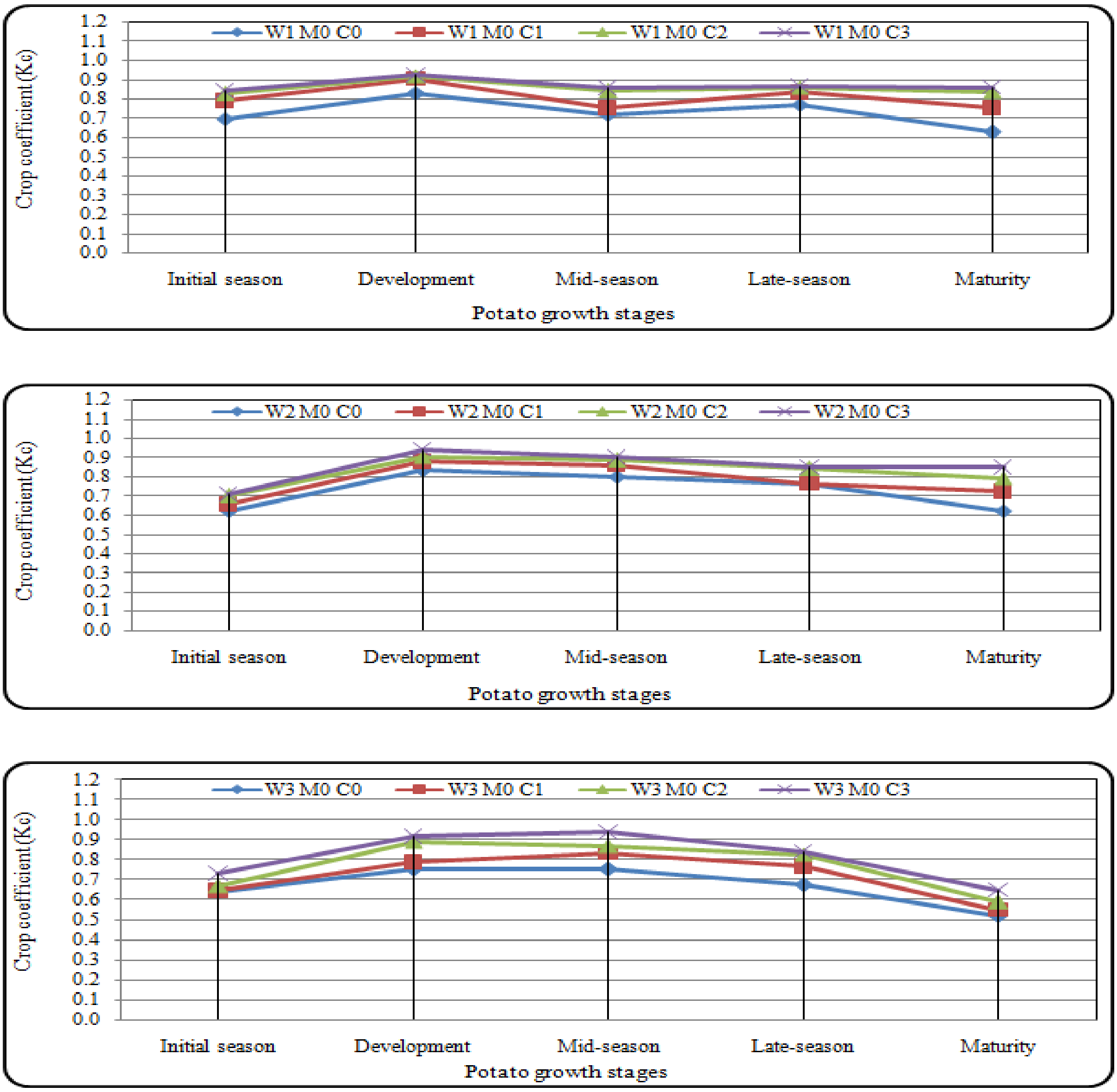


**Fig.(60): Effect of compost on crop coefficient ($K_c$) under different water regimes in non-mulched soil**. Where: W1, W2 and W3 = water regime at 100, 80 and 60 % of $ET_c$ respectively. M0, M1 = without mulch, with mulch (24 ton/ha), respectively. C0, C1, C2 and C3 = Compost at 0, 12, 24 and 36 ton/ha, respectively.

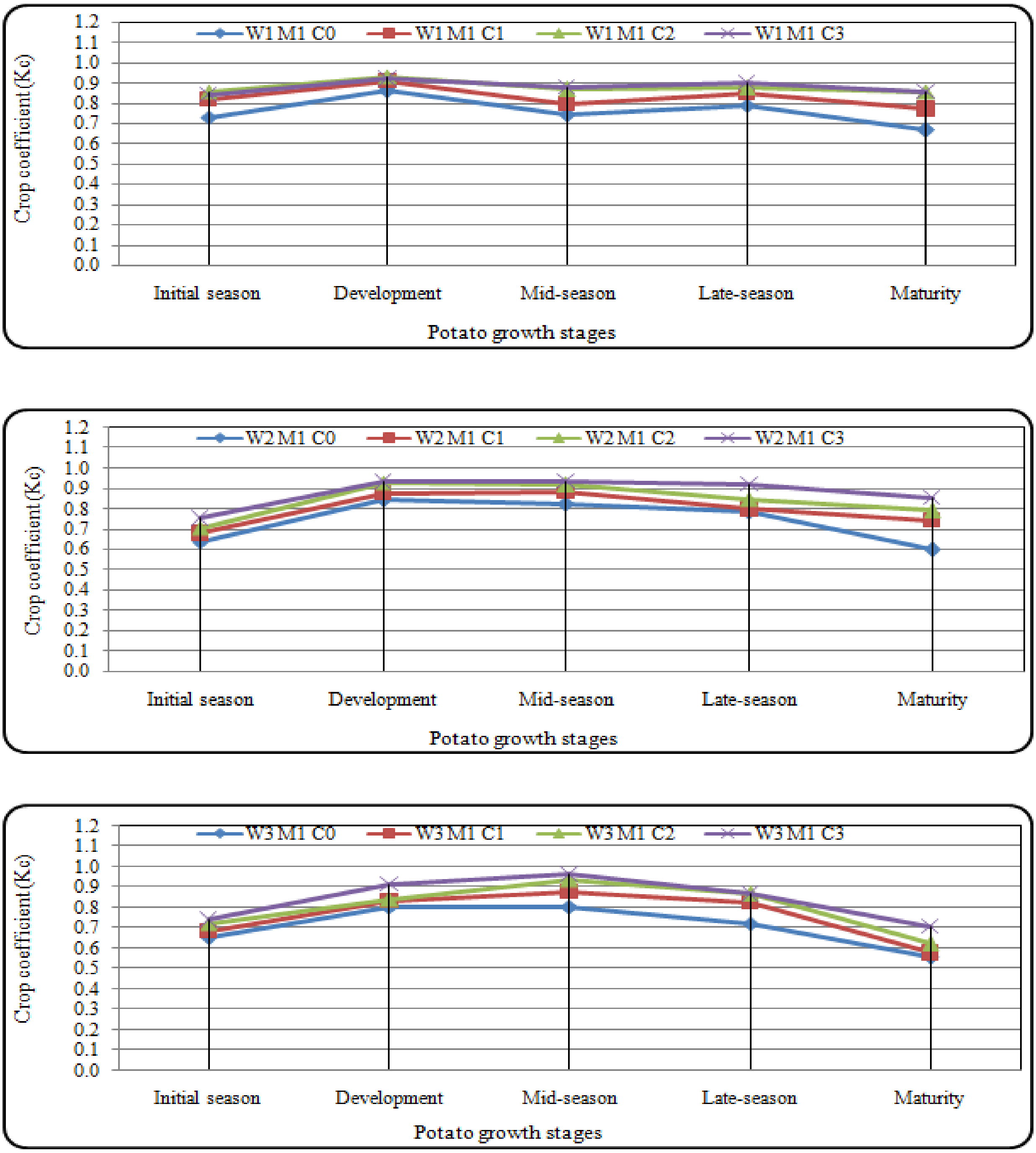


**Fig.(61): Effect of compost on crop coefficient (Kc) under different water regimes in mulched soil.** Where: W1, W2 and W3 = water regime at 100, 80 and 60 % of $ET_c$ respectively. M0, M1 = without mulch, with mulch (24 ton/ha), respectively. C0, C1, C2 and C3 = Compost at 0, 12, 24 and 36 ton/ha, respectively.

### *5.3.4. Water economy and water use efficiency of potato (kg $m^{-3}$):*

The essential object of water management is the improvement of water use regime that will provide maximum yield per unit of water consumed by plants. Water-use efficiency measures are commonly used to characterize the water-conserving potential of irrigation systems. Alternative efficiency measures reflect various stages of water use and levels of spatial aggregation (UN-water, 2007). Thus, water economy and water use efficiency may be used as criteria for the relation between water applied and also water consumed by plants throughout the growth stages, and total crop yield.

Water economy and water use efficiency as affected by compost, mulch, water regimes and their interactions are presented in tables (36-39) and illustrated in figures (62-67).

Data in hand showed the following:-

#### *5.3.4.1. General effect of individual factors on water economy and water use efficiency :-*

Data shown in figure (62, 64) showed the effect of incorporating compost at three rates (12, 24, 36 ton $ha^{-1}$) compared to that of soil didn't receive compost on water economy and water use efficiency by potato plants. It could be noticed that there was a significant increase in either water economy or water use efficiency under all application rates of compost.

Obtained data explained the effect of soil mulching on water economy and water use efficiency for potato crop. It could be observed that mulching the soil with dried sugar cane wastes slightly increased water economy.

In contrast, it could be noticed that soil mulching slightly reduced the values of water use efficiency. Comparing the water use efficiency for the mulched soil to that of the non-mulched one, water use efficiency of the former was lower than that of the latter by 2.7 %.

Data illustrated in figure (63, 65) explained the effect of applying three water regimes to the soil i.e. 100 %, 80 % and 60 % of $ET_{crop}$. It's obvious that either the values water economy or water use efficiency considerably decreased with increasing the amounts of irrigation water from 60 to 100% of the $ET_c$, as applying the amounts of irrigation water equals to the 60 % of the $ET_c$ attained the highest values for both of water economy and water use efficiency.

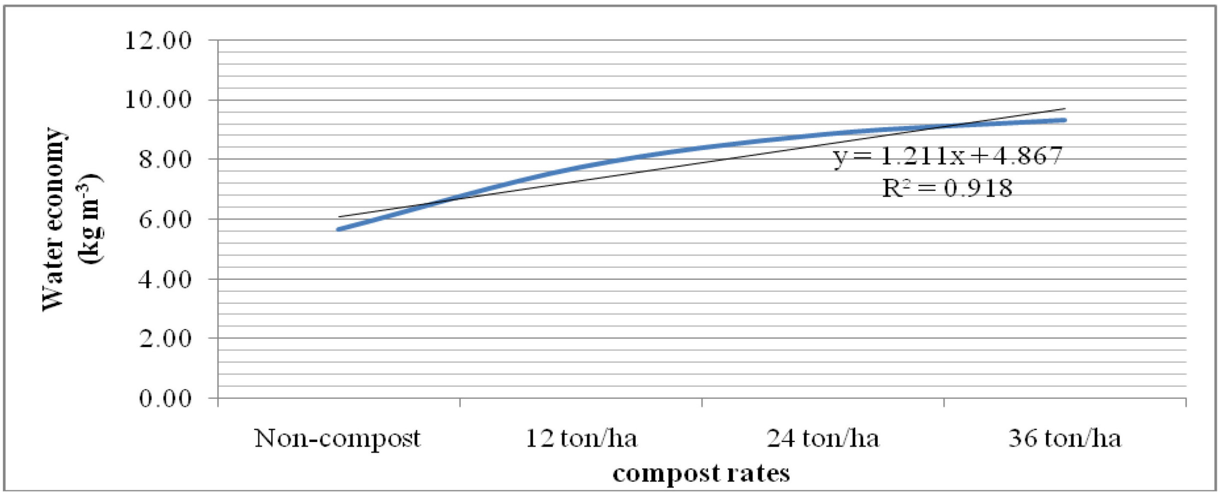


**Fig.(62): Effect of compost rates on water economy**

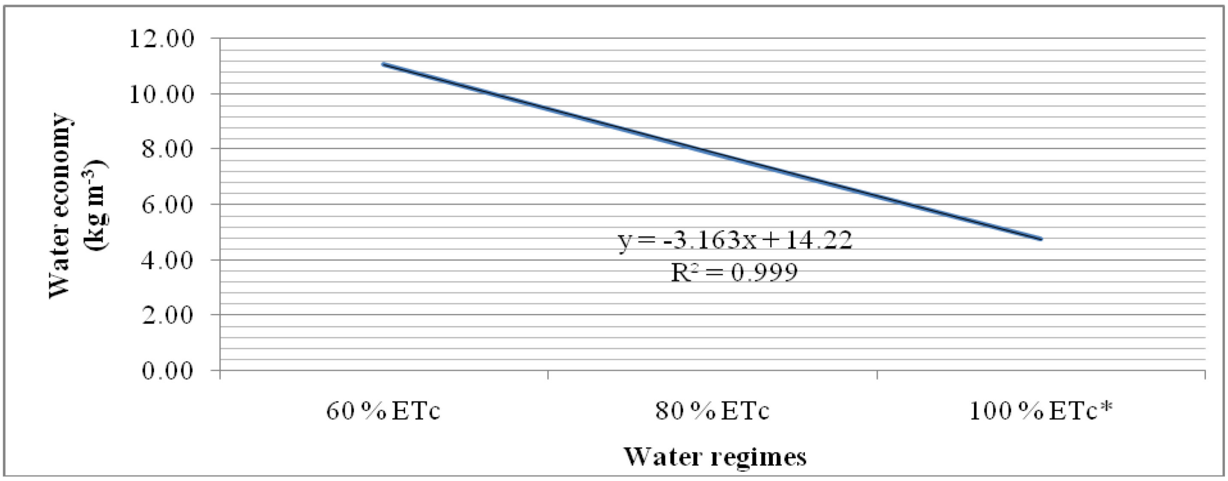


**Fig.(63): Effect of water regimes on water economy**

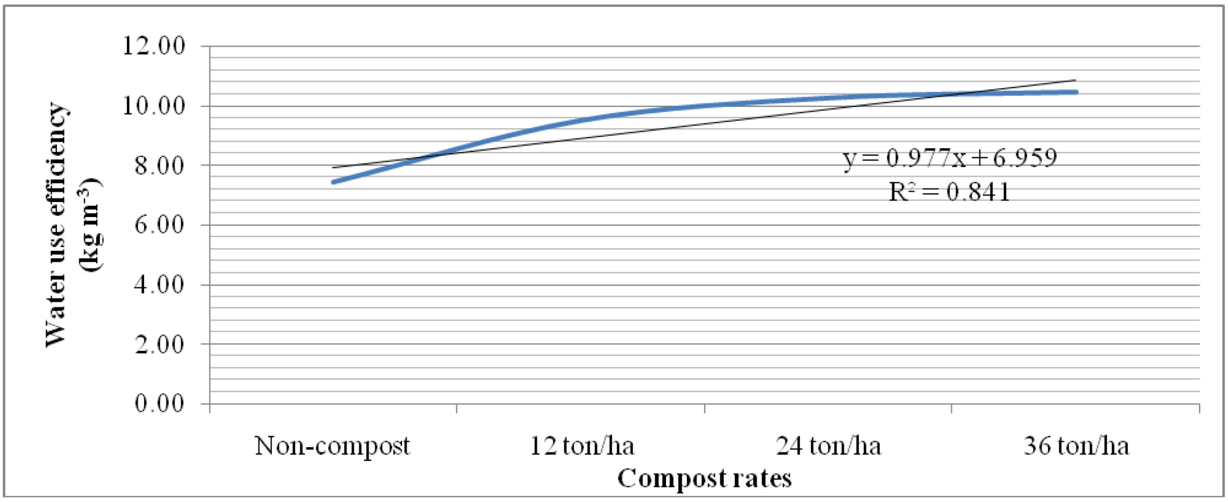


**Fig. (64): Effect of compost on water use efficiency**

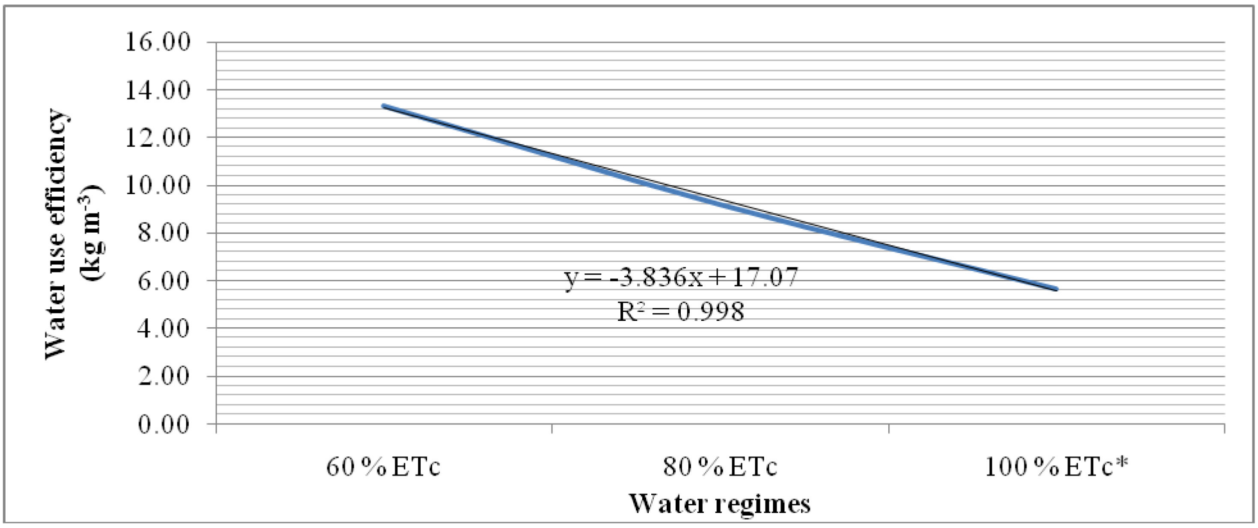


**Fig.(65): Effect of water regimes on water use efficiency**

***5.3.4.2. Effect of interactions among the studied factors on water economy and water use efficiency:***

Tables (36-39) showed the influence of the double and triple interactions between water regimes, mulch and compost on water economy and water use efficiency as follows:-

Regarding the interaction between water regime and mulch, it could be detected that decreasing water regimes with mulch increased water economy and water use efficiency.

**Table (36): Effect of the interaction between water regimes and soil mulching on water economy and water use efficiency (kg m$^{-3}$)**

| Water regime | Mulch | Water economy (kg m$^{-3}$) | Water use efficiency (kg m$^{-3}$) |
|---|---|---|---|
| 100 % of ET$_c$* | Non-mulch | 5.10 | 6.14 |
| | Mulch | 4.41 | 5.18 |
| 80 % of ET$_c$ | Non-mulch | 7.72 | 9.16 |
| | Mulch | 8.00 | 9.26 |
| 60 % of ET$_c$ | Non-mulch | 10.81 | 13.29 |
| | Mulch | 11.34 | 13.38 |
| LSD at 5% | | 0.142 | 0.174 |
| LSD at 1% | | 0.216 | 0.264 |

* = 4000 m³/ha

The highest values of water economy (11.34 kg $m^{-3}$) and water use efficiency (13.38 kg $m^{-3}$) were achieved under irrigation using 60 % of the $ET_c$ in mulched soil, while the lowest values of water economy (4.40 kg $m^{-3}$) and water use efficiency (5.18 kg $m^{-3}$) were due to applying 100 % of the $ET_c$ to the mulched soil.

As to the effect of interaction between water regime and compost on water economy and water use efficiency, the obtained results represented in table (37) stated clearly that decreasing irrigation water levels combined with increasing applying compost rates led to increase water economy and water use efficiency, except for the combination of 100 % of the $ET_c$ and 36 ton $ha^{-1}$compost rate.

**Table (37): Effect of interaction between water regimes and compost on water economy and water use efficiency**

| Water regime | Compost | Water economy (kg $m^{-3}$) | Water use efficiency (kg $m^{-3}$) |
|---|---|---|---|
| 100 % of $ET_c$* | Non-compost | 3.85 | 5.06 |
| | 12 ton/ha | 4.67 | 5.68 |
| | 24 ton/ha | 5.28 | 6.03 |
| | 36 ton/ha | 5.21 | 5.89 |
| 80 % of $ET_c$ | Non-compost | 6.17 | 7.84 |
| | 12 ton/ha | 7.33 | 8.78 |
| | 24 ton/ha | 8.58 | 9.80 |
| | 36 ton/ha | 9.36 | 10.40 |
| 60 % of $ET_c$ | Non-compost | 6.95 | 9.39 |
| | 12 ton/ha | 11.25 | 14.02 |
| | 24 ton/ha | 12.68 | 14.90 |
| | 36 ton/ha | 13.43 | 15.03 |
| **LSD at 5%** | | **0.12** | **0.14** |
| **LSD at 1%** | | **0.16** | **0.19** |

* = 4000 m³/ha

Applying 36 ton $ha^{-1}$ of compost + 60 % of the $ET_c$ attained the highest values of water economy (13.4 kg $m^{-3}$) and water use efficiency (15.03 kg $m^{-3}$). But there were insignificant differences between the interaction of (36 ton $ha^{-1}$compost rate + 60 % of the $ET_c$) and interaction of (24 ton $ha^{-1}$compost rate + 60 % of the $ET_c$). However, the interaction of (without compost + 100 % of the $ET_c$) gave the lowest values of water economy (3.85 kg $m^{-3}$) and water use efficiency (5.06 kg $m^{-3}$).

Respecting the influence of interaction between compost and mulch, data detected that increasing applied compost rates with soil covering notably increased escalating for water economy. As increasing applied compost rate at 0 and 12 ton $ha^{-1}$with soil covering increased water economy compared to applying compost at the same rates without soil covering. But subsequently these increases in water economy were declining by increasing compost rates with soil covering; in addition, the differences were slight between applying compost rate at 24 and 36 ton $ha^{-1}$(table 38).

**Table (38): Effect of the interaction between soil mulching and compost on water economy and water use efficiency (kg $m^{-3}$)**

| Mulch | Compost | Water economy (kg $m^{-3}$) | Water use efficiency (kg $m^{-3}$) |
|---|---|---|---|
| Non-mulch | **Non-compost** | 5.51 | 7.40 |
| | **12 ton/ha** | 7.67 | 9.58 |
| | **24 ton/ha** | 8.84 | 10.39 |
| | **36 ton/ha** | 9.49 | 10.75 |
| Mulch | **Non-compost** | 5.80 | 7.47 |
| | **12 ton/ha** | 7.83 | 9.41 |
| | **24 ton/ha** | 8.86 | 10.10 |
| | **36 ton/ha** | 9.17 | 10.13 |
| **LSD at 5%** | | **0.10** | **0.12** |
| **LSD at 1%** | | **0.13** | **0.16** |

On the other hand, considerable increases in water use efficiency were declining by increasing applied compost rates with soil covering compared to applying compost at the same rates without soil covering, except for none composted soil, the increase was escalating.

The highest values of water economy (9.48 kg $m^{-3}$) and water use efficiency (10.75 kg $m^{-3}$) were attained by incorporating 36 ton $ha^{-1}$ of compost in non-mulched soil. However, the lowest values were obtained from the same soil that didn't receive compost.

Concerning the effect of triple interaction among water regime, mulch and compost, as for data shown in table (39) and figures (66-67), the decrement in applied water with increasing applied compost rates obviously increased water economy and water use efficiency in mulched and non-mulched soils. Except for 100 % of $ET_c$ as the main plot, soil mulching reduced water economy and water use efficiency with all incorporating compost rates in the mulched soil compared to non mulched soil. Highly negative effect for water economy and water use efficiency was observed under 100 % of the $ET_c$ in mulched soil that was not treated with compost.

The highest values for water economy (13.62 kg $m^{-3}$) and water use efficiency (15.06 kg $m^{-3}$) were achieved by the combination of (60 % of the $ET_c$+ soil mulching + with applying 36 ton $ha^{-1}$ of compost). While the lowest values for water economy (3.68 kg $m^{-3}$) and water use efficiency (4.75 kg $m^{-3}$) were recorded by the combination of (100 % of the $ET_c$ + soil mulching + with no applying compost ).

**Table (39): Effect of the interaction among water regimes, mulch and compost on water use efficiency and water economy**

| Property | Water regime | Mulch | Compost | | | |
|---|---|---|---|---|---|---|
| | | | Non-compost | 12 ton/ha | 24 ton/ha | 36 ton/ha |
| Water economy kg/m³ | 100 % of $ET_c$* | Non-mulch | 4.02 | 4.84 | 5.55 | 5.99 |
| | | Mulch | 3.68 | 4.50 | 5.02 | 4.42 |
| | 80 % of $ET_c$ | Non-mulch | 6.03 | 7.18 | 8.41 | 9.25 |
| | | Mulch | 6.31 | 7.49 | 8.74 | 9.47 |
| | 60 % of $ET_c$ | Non-mulch | 6.49 | 10.98 | 12.56 | 13.23 |
| | | Mulch | 7.41 | 11.52 | 12.81 | 13.62 |
| | LSD at 5% | | 0.166 | | | |
| | LSD at 1% | | 0.222 | | | |
| Water use efficiency kg/m³ | 100 % of ETc | Non-mulch | 5.37 | 5.98 | 6.41 | 6.83 |
| | | Mulch | 4.75 | 5.38 | 5.66 | 4.95 |
| | 80 % of $ET_c$ | Non-mulch | 7.76 | 8.69 | 9.73 | 10.44 |
| | | Mulch | 7.93 | 8.88 | 9.87 | 10.35 |
| | 60 % of $ET_c$ | Non-mulch | 9.06 | 14.08 | 15.03 | 15.00 |
| | | Mulch | 9.72 | 13.96 | 14.77 | 15.07 |
| | LSD at 5% | | 0.204 | | | |
| | LSD at 1% | | 0.272 | | | |

* = 4000 $m^3$/ha

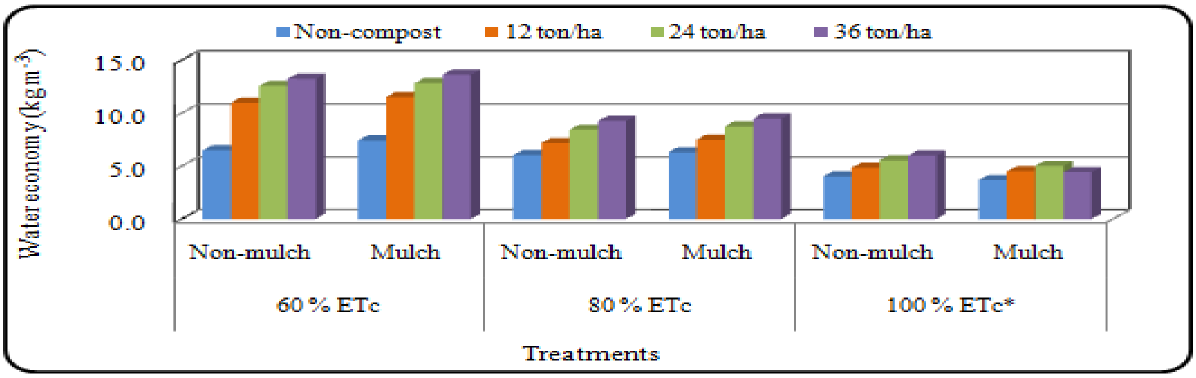


**Fig.(66): Effect of the interaction among water regimes, mulch and compost on water economy**

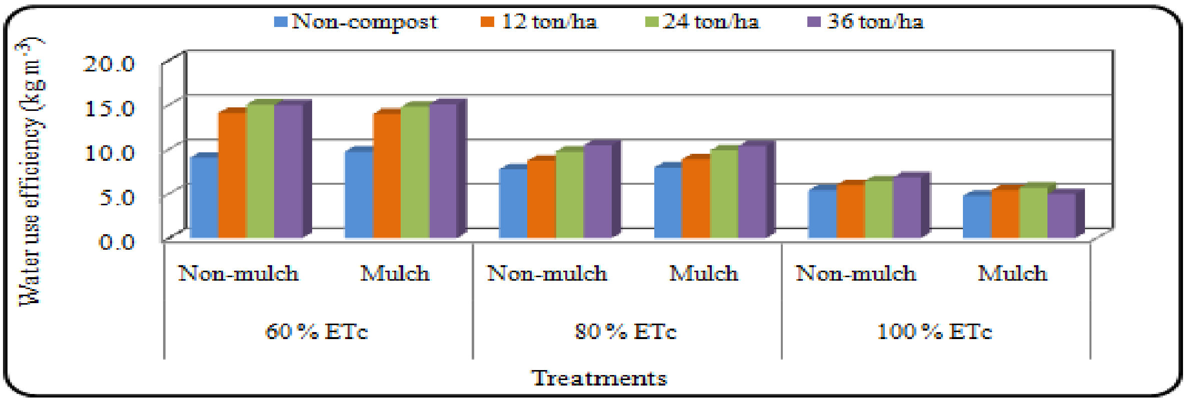


**Fig.(67): Effect of the interaction among water regimes, mulch and compost on water use efficiency**

### *5.3.5. Effect on water application efficiency (WAE):-*

Water application efficiency is the ratio of the average depth of irrigation water stored in the root zone for crop consumptive use to the average depth applied, expressed as a percentage (UN-water, 2007). Data in table (40) explained general effect of compost, mulching the soil and water regimes, and the triple interactions between them on water application efficiency.

#### *5.3.5.1. General effect of the individual factors :*

Referring to the effect of compost rates, incorporating compost in the soil noticeably increased water application efficiency compared to the soil that didn't receive compost. Increments in WAE of the soil treated with compost compared to that of the soil didn't receive compost were 7.5, 13.8 and 17.1 % for the applying 12, 24 and 36 ton $ha^{-1}$ of compost, respectively.

As well the effect of mulching on water application efficiency, it could be noticed that soil mulching generally increased the values of WAE under all treatments of applying compost and water regimes. Comparing WAE in the mulched soil to that in the non-mulched one, WAE of the former was higher than that of the latter by 3.2 %.

On the other hand, data in hand declared that increasing applied water from 60 to 80 % of $ET_c$ increased WAE but decreased it with increasing applied water by 100 $ET_c$. In detail, increments in WAE were 3.4 and 1.8 % that of the soil received 60 % of its $ET_c$ for the soils that received 80 % and 100 % of their $ET_c$, in sequence.

**Table (40): Effect of compost and mulch on water application efficiency under different drip water regimes**

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 74.53 | 77.21 | **75.87** |
| | 12 ton/ha | 80.63 | 83.27 | **81.95** |
| | 24 ton/ha | 86.22 | 88.37 | **87.30** |
| | 36 ton/ha | 87.43 | 88.93 | **88.18** |
| | Mean | **82.20** | **84.44** | **83.32** |
| 80 % of $ET_c$ | Non-compost | 77.49 | 79.32 | **78.41** |
| | 12 ton/ha | 82.32 | 84.13 | **83.22** |
| | 24 ton/ha | 86.19 | 88.26 | **87.22** |
| | 36 ton/ha | 88.28 | 91.20 | **89.74** |
| | Mean | **83.57** | **85.73** | **84.65** |
| 60 % of $ET_c$ | Non-compost | 71.29 | 75.95 | **73.62** |
| | 12 ton/ha | 77.70 | 82.16 | **79.93** |
| | 24 ton/ha | 83.21 | 86.42 | **84.82** |
| | 36 ton/ha | 87.87 | 90.04 | **88.95** |
| | Mean | **80.02** | **83.64** | **81.83** |
| | Mean | **81.93** | **84.60** | |
| Grand mean | | | | **83.27** |

**Mean of compost**

| Compost | Water regime | | | Mean |
|---|---|---|---|---|
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| Non-compost | 75.87 | 78.41 | 73.62 | **75.97** |
| 12 ton/ha | 81.95 | 83.22 | 79.93 | **81.70** |
| 24 ton/ha | 87.30 | 87.22 | 84.82 | **86.44** |
| 36 ton/ha | 88.18 | 89.74 | 88.95 | **88.96** |
| Mean | **83.32** | **84.65** | **81.83** | **83.27** |

* = 4000 $m^3$/ha

### 5.3.5.2. ***Effect of the triple interaction among water regime, mulch and compost on water application efficiency:***

As for data in table (40), it could be observed that the triple interaction among water regimes, mulch and compost rates resulted in a significant difference in water application efficiency. In other words, the increment in applied water with increasing applied compost rates increased WAE in mulched soil compared to non mulched one. The maximum water application efficiency (91.2 %) was achieved by the combination of (80 % of $ET_c$ water regime + mulching the soil + applying compost rate of 36 ton $ha^{-1}$). On the other hand, the minimum water application efficiency (71.3 %) was obtained by the combination of (60 % of $ET_c$ water regime + non-mulching the soil + with no applying compost).

## 5.4. ***Fertilizer use efficiencies of nitrogen, phosphorus and potassium :-***

Obtained results in tables (41-43) and figures (68-73) indicated the general effect of compost, soil mulching and water regimes, and the triple interactions between them on nitrogen, phosphorus and potassium fertilizers use efficiencies for potato plant.

### 5.4.1. ***General effect of individual factors on fertilizer use efficiencies***

Incorporating compost in the soil clearly increased nitrogen, phosphorus and potassium fertilizers use efficiencies. The more the amount of applied compost was, the higher was the fertilizer use efficiency. In other words, increments in nitrogen, phosphorus and potassium fertilizers use efficiencies of potato plants that treated with compost, compared to that didn't receive compost were 33.4, 52.4 and 60.1 % of nitrogen, phosphorus and potassium due to applying 12, 24 and 36 ton $ha^{-1}$ of compost, respectively.

On the other hand, it can be noticed that soil mulching slightly decreased the values of nitrogen, phosphorus and potassium fertilizers use efficiencies for potato plants. Comparing in the mulched soil to that in the non-mulched one, nitrogen, phosphorus and potassium fertilizers use efficiencies of the former were 99.2 % of the latter.

Regarding the effect of water regimes, data in hand reveal that increasing applied water to the soil decreased nitrogen, phosphorus and potassium fertilizers use efficiencies. Decrements in nitrogen, phosphorus and potassium fertilizers use efficiencies for plants were 5.4 and 28.5 % that of the plants received 60 % of its $ET_c$ for the soils that received 80 % and 100 % of their $ET_c$, in sequence.

### *5.4.2. Effect of the triple interaction among water regime, mulch and compost on fertilizer use efficiencies :*

There were different effects of the triple interaction among water regimes, mulch and compost rates on nitrogen, phosphorus and potassium fertilizer use efficiencies. The decrement in applied water with increasing applied compost rates increased nitrogen, phosphorus and potassium fertilizer use efficiencies in mulched soil and none mulched one.

The maximum nitrogen, phosphorus and potassium fertilizer use efficiencies were attained by the combination of (60 % of $ET_c$ water regime + with soil mulching + applying compost rate of 36 ton $ha^{-1}$). On the other hand, the minimum nitrogen, phosphorus and potassium fertilizer use efficiencies were recorded by the combination of (100 % of $ET_c$ water regime + with soil mulching + without applying compost).

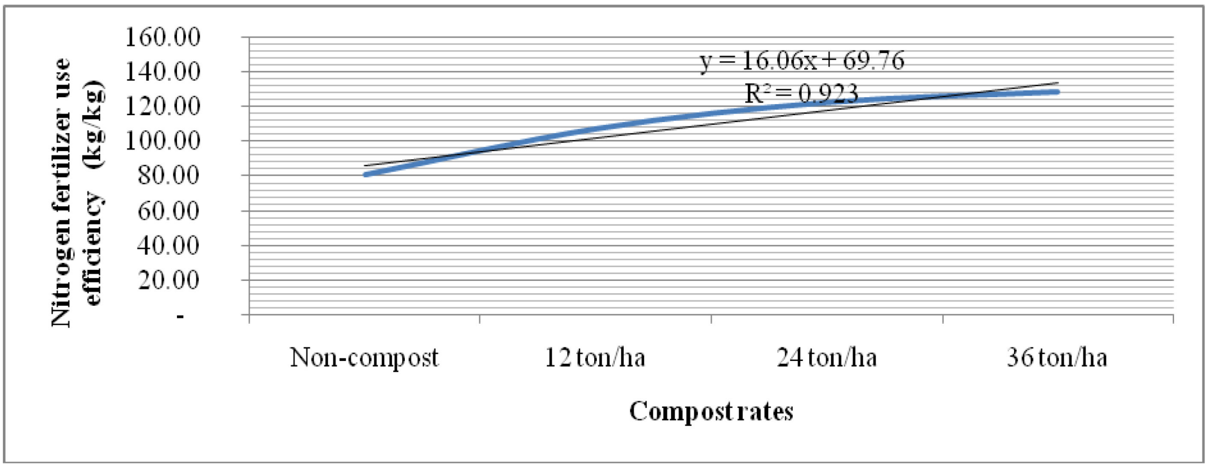


**Fig.(68): Effect of compost rates on nitrogen fertilizer use efficiency**

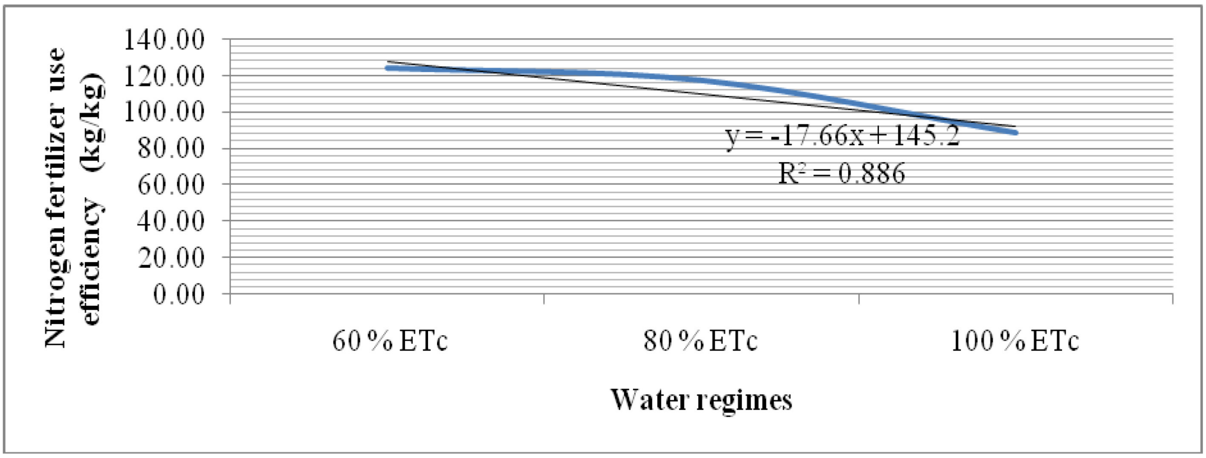


**Fig.(69): Effect of water regimes on nitrogen fertilizer use efficiency**

**Table (41) Effect of compost and mulch on nitrogen fertilizer use efficiency (kg/kg) under different water regimes**

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 74.92 | 68.70 | 71.81 |
| | 12 ton/ha | 90.22 | 83.85 | 87.03 |
| | 24 ton/ha | 103.44 | 93.59 | 98.51 |
| | 36 ton/ha | 111.73 | 82.44 | 97.09 |
| | **Mean** | **95.08** | **82.14** | **88.61** |
| 80 % of $ET_c$ | Non-compost | 89.96 | 94.10 | 92.03 |
| | 12 ton/ha | 107.07 | 111.73 | 109.40 |
| | 24 ton/ha | 125.47 | 130.40 | 127.94 |
| | 36 ton/ha | 137.92 | 141.29 | 139.60 |
| | **Mean** | **115.10** | **119.38** | **117.24** |
| 60 % of $ET_c$ | Non-compost | 72.59 | 82.96 | 77.77 |
| | 12 ton/ha | 122.88 | 128.84 | 125.86 |
| | 24 ton/ha | 140.47 | 143.36 | 141.92 |
| | 36 ton/ha | 148.03 | 152.43 | 150.23 |
| | **Mean** | **120.99** | **126.90** | **123.95** |
| | **Mean** | **110.39** | **109.47** | |
| **Grand mean** | | | | **109.93** |

**Mean of compost**

| Compost | Water regime | | | Mean |
|---|---|---|---|---|
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| Non-compost | 71.82 | 92.03 | 77.77 | **80.54** |
| 12 ton/ha | 87.03 | 109.40 | 125.86 | **107.43** |
| 24 ton/ha | 98.51 | 127.94 | 141.92 | **122.79** |
| 36 ton/ha | 97.11 | 139.60 | 150.23 | **128.98** |
| **Mean** | **88.61** | **117.24** | **123.95** | **109.93** |

* = 4000 $m^3$/ha

Table (42) Effect of compost and mulch on phosphorus fertilizer use efficiency (kg/kg) under different water regimes

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 112.43 | 103.10 | 107.77 |
| | 12 ton/ha | 135.39 | 125.83 | 130.61 |
| | 24 ton/ha | 155.23 | 140.45 | 147.84 |
| | 36 ton/ha | 167.68 | 123.72 | 145.70 |
| | **Mean** | **142.68** | **123.27** | **132.98** |
| 80 % of $ET_c$ | Non-compost | 135.00 | 141.22 | 138.11 |
| | 12 ton/ha | 160.68 | 167.68 | 164.18 |
| | 24 ton/ha | 188.30 | 195.69 | 191.99 |
| | 36 ton/ha | 206.97 | 212.03 | 209.50 |
| | **Mean** | **172.74** | **179.15** | **175.95** |
| 60 % of $ET_c$ | Non-compost | 108.93 | 124.49 | 116.71 |
| | 12 ton/ha | 184.41 | 193.36 | 188.88 |
| | 24 ton/ha | 210.81 | 215.14 | 212.97 |
| | 36 ton/ha | 222.14 | 228.76 | 225.45 |
| | **Mean** | **181.57** | **190.44** | **186.00** |
| | **Mean** | **165.66** | **164.29** | |
| **Grand mean** | | | | **164.98** |

| Compost | Water regime | | | Mean |
|---|---|---|---|---|
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| Non-compost | 107.77 | 138.11 | 116.71 | **120.87** |
| 12 ton/ha | 130.60 | 164.18 | 188.88 | **161.22** |
| 24 ton/ha | 147.83 | 191.99 | 212.97 | **184.27** |
| 36 ton/ha | 145.73 | 209.50 | 225.45 | **193.56** |
| **Mean** | **132.98** | **175.95** | **186.00** | **164.98** |

(Mean of compost)

* = 4000 m³/ha

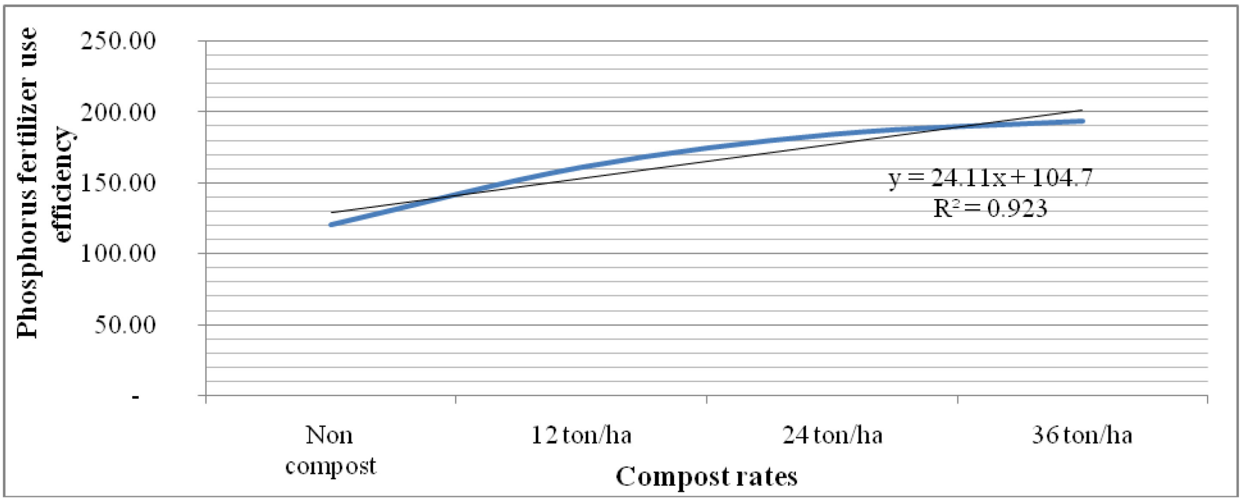


Fig.(70): Effect of compost rates on phosphorus fertilizer use efficiency

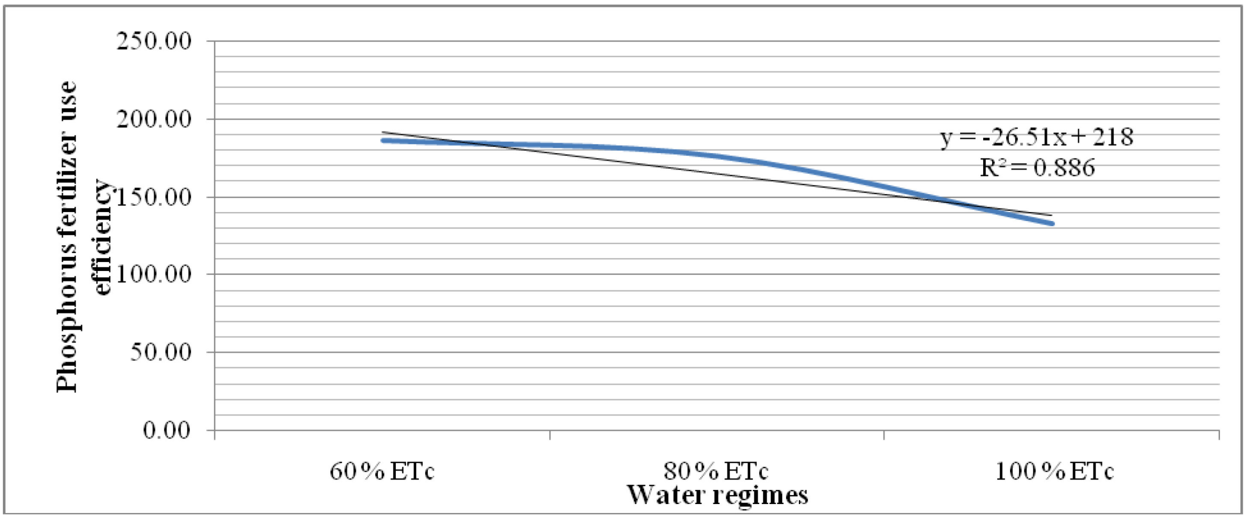


**Fig.(71): Effect of water regimes on phosphorus fertilizer use efficiency (kg/kg)**

**Table (43) Effect of compost and mulch on potassium fertilizer use efficiency (kg/kg) under different water regimes**

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 70.23 | 64.40 | **67.32** |
| | 12 ton/ha | 84.57 | 78.60 | **81.59** |
| | 24 ton/ha | 96.97 | 87.73 | **92.35** |
| | 36 ton/ha | 104.74 | 77.28 | **91.01** |
| | Mean | **89.13** | **77.00** | **83.07** |
| 80 % of $ET_c$ | Non-compost | 84.33 | 88.22 | **86.27** |
| | 12 ton/ha | 100.37 | 104.74 | **102.56** |
| | 24 ton/ha | 117.62 | 122.24 | **119.93** |
| | 36 ton/ha | 129.29 | 132.45 | **130.87** |
| | Mean | **107.90** | **111.91** | **109.91** |
| 60 % of $ET_c$ | Non-compost | 68.05 | 77.77 | **72.91** |
| | 12 ton/ha | 115.19 | 120.78 | **117.99** |
| | 24 ton/ha | 131.68 | 134.39 | **133.04** |
| | 36 ton/ha | 138.77 | 142.90 | **140.83** |
| | Mean | **113.42** | **118.96** | **116.19** |
| | Mean | **103.49** | **102.63** | |
| Grand mean | | | | **103.06** |

**Mean of compost**

| Compost | Water regime | | | Mean |
|---|---|---|---|---|
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| Non-compost | 67.32 | 86.27 | 72.91 | **75.50** |
| 12 ton/ha | 81.58 | 102.56 | 117.99 | **100.71** |
| 24 ton/ha | 92.34 | 119.93 | 133.04 | **115.11** |
| 36 ton/ha | 91.03 | 130.87 | 140.83 | **120.91** |
| Mean | **83.07** | **109.91** | **116.19** | **103.06** |

* = 4000 $m^3$/ha

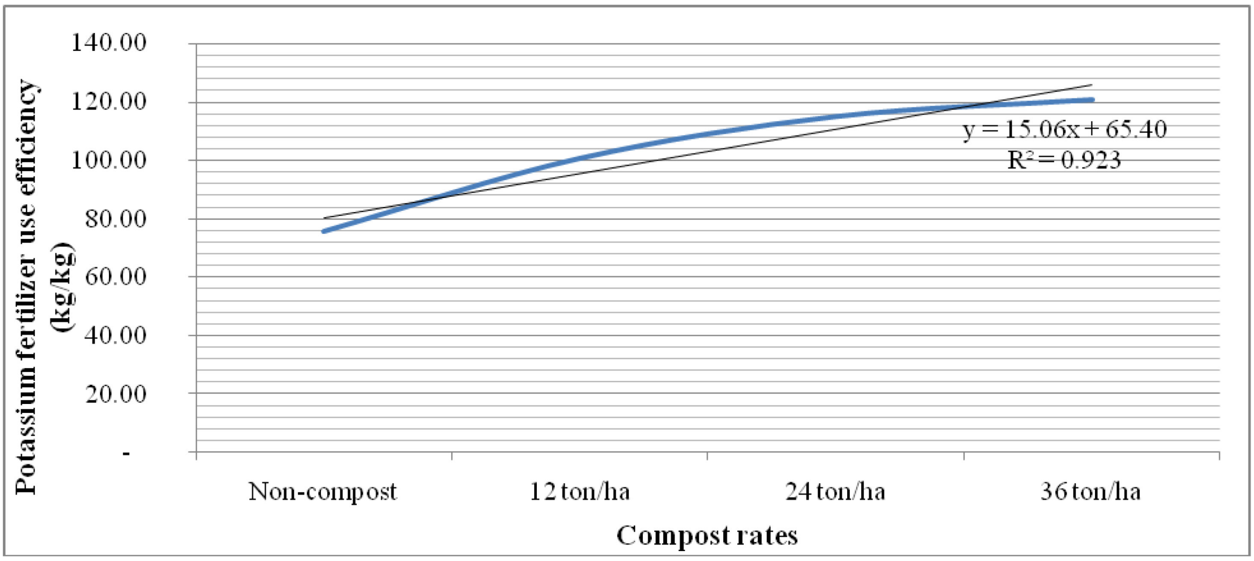


**Fig.(72): Effect of compost rates on potassium fertilizer use efficiency**

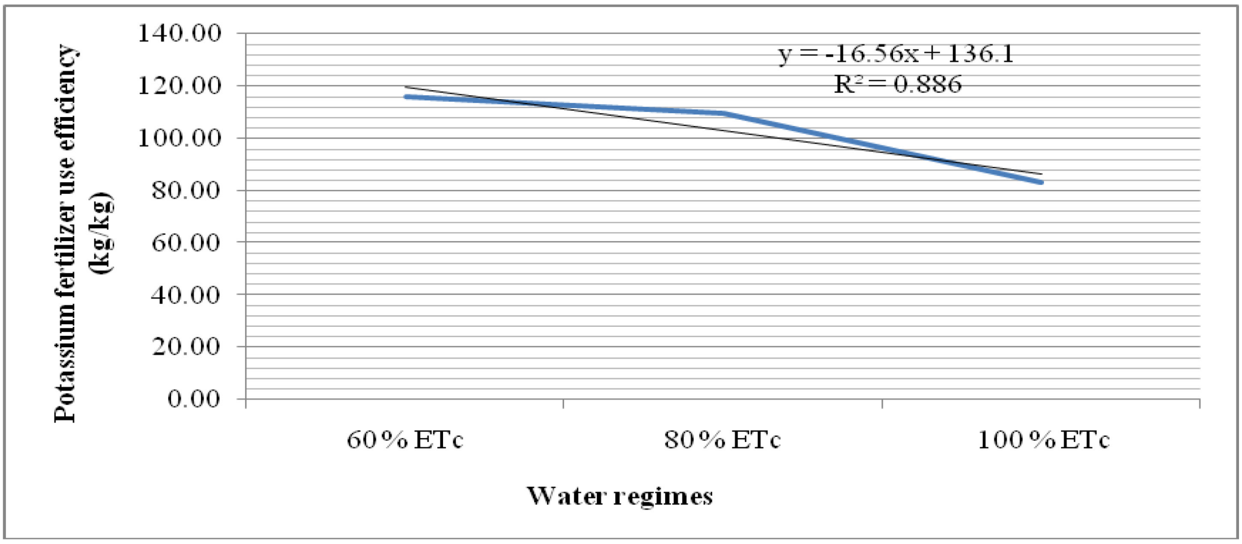


**Fig.(73): Effect of water regimes on potassium fertilizer use efficiency**

## 5.5. *Economic analysis*

Costs (inputs) and profits (outputs) were calculated according to the sale prices in Egypt 2010/2011; the home sale price for local potato consumption was 1800 LE/ton (Oboor Market, 2011) equal to 225 Euro/ton (Euro = 8.0 LE), while the average export price for potato from Egypt to Europe 2010/2011 was 400 €/ton (UN- Comtrade, available online). Data on drip irrigation system costs are given in table (44), it is obvious that while the fixed cost (depreciation + interest + taxes and overheads) of the drip irrigation system were 74.40, 125.00 and 17.86 Euro/ year respectively, the variable costs (labor, power and repair& maintenance) were 43.45, 26.32 and 17.86 Euro/ year in the same sequence. Data obtained in table (45) showed the total irrigation costs (Euro/ ha) were 101.63, 81.30 and 60.98 Euro for 100 % of $ET_c$, 80 % of $ET_c$, and 60 % of $ET_c$ respectively. According to the previously mentioned costs could be arranged in the following ascending order: 60 % of $ET_c$ < 80 % of $ET_c$ < 100 % of $ET_c$.

**Table (44): Costs of irrigation**

| Items of drip irrigation system costs | | Value (Euro**/ha/year) |
|---|---|---|
| **Investment** | | 892.86 |
| **Fixed Costs** | **Depreciation** | 74.40 |
| | **Interest** | 125.00 |
| | **Taxes &Overheads** | 17.86 |
| | **Total** | 217.26 |
| **Variable Costs** | **Labor** | 43.45 |
| | **Power** | 26.32 |
| | **Repair &maintenance** | 17.86 |
| | **Total** | 87.63 |
| **Total Cost/ year** | | 304.89 |
| **Total Cost for potato/ season (4 month) (100 % of $ET_c$)** | | 101.63 |

* = 4000 m³/ha, **Euro= 8.0 L.E.

Tables (45-48) and figures (74-79) illustrated the total production costs (Euro/ha), potato tuber yield (ton/ ha), the profit and the net profit (Euro/ ha) for local consumption in Egypt and for exportation, respectively.

Table (45): Total costs (Euro**/ha) of potato production under different compost rates, mulch and water

| Water regime | Mulch | Compost | Items of Costs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Preparing of soil | Tuber seeds | Irrigation | Mulch | Compost | Fertilizers NPK | Pest control | Weed control | Harvesting | Total costs |
| 100 % of $ET_c$* | Non-mulch | Non- | 53.57 | 684.53 | 101.63 | 0.0 | 0.0 | 471.8 | 29.8 | 56.55 | 59.53 | 1457.36 |
| | | 12 ton/ha | 53.57 | 684.53 | 101.63 | 0.0 | 412.5 | 471.8 | 29.8 | 56.55 | 59.53 | 1869.86 |
| | | 24 ton/ha | 53.57 | 684.53 | 101.63 | 0.0 | 825.0 | 471.8 | 29.8 | 56.55 | 59.53 | 2282.36 |
| | | 36 ton/ha | 53.57 | 684.53 | 101.63 | 0.0 | 1237.5 | 471.8 | 29.8 | 56.55 | 59.53 | 2694.86 |
| | Mulch | Non- | 53.57 | 684.53 | 101.63 | 150 | 0.0 | 471.8 | 29.8 | 56.55 | 59.53 | 1607.36 |
| | | 12 ton/ha | 53.57 | 684.53 | 101.63 | 150 | 412.5 | 471.8 | 29.8 | 56.55 | 59.53 | 2019.86 |
| | | 24 ton/ha | 53.57 | 684.53 | 101.63 | 150 | 825.0 | 471.8 | 29.8 | 56.55 | 59.53 | 2432.36 |
| | | 36 ton/ha | 53.57 | 684.53 | 101.63 | 150 | 1237.5 | 471.8 | 29.8 | 56.55 | 59.53 | 2844.86 |
| 80 % of $ET_c$ | Non-mulch | Non- | 53.57 | 684.53 | 81.30 | 0.0 | 0.0 | 471.8 | 29.8 | 56.55 | 59.53 | 1437.03 |
| | | 12 ton/ha | 53.57 | 684.53 | 81.30 | 0.0 | 412.5 | 471.8 | 29.8 | 56.55 | 59.53 | 1849.53 |
| | | 24 ton/ha | 53.57 | 684.53 | 81.30 | 0.0 | 825.0 | 471.8 | 29.8 | 56.55 | 59.53 | 2262.03 |
| | | 36 ton/ha | 53.57 | 684.53 | 81.30 | 0.0 | 1237.5 | 471.8 | 29.8 | 56.55 | 59.53 | 2674.53 |
| | Mulch | Non- | 53.57 | 684.53 | 81.30 | 150 | 0.0 | 471.8 | 29.8 | 56.55 | 59.53 | 1587.03 |
| | | 12 ton/ha | 53.57 | 684.53 | 81.30 | 150 | 412.5 | 471.8 | 29.8 | 56.55 | 59.53 | 1999.53 |
| | | 24 ton/ha | 53.57 | 684.53 | 81.30 | 150 | 825.0 | 471.8 | 29.8 | 56.55 | 59.53 | 2412.03 |
| | | 36 ton/ha | 53.57 | 684.53 | 81.30 | 150 | 1237.5 | 471.8 | 29.8 | 56.55 | 59.53 | 2824.53 |
| 60 % of $ET_c$ | Non-mulch | Non- | 53.57 | 684.53 | 60.98 | 0.0 | 0.0 | 471.8 | 29.8 | 56.55 | 59.53 | 1416.71 |
| | | 12 ton/ha | 53.57 | 684.53 | 60.98 | 0.0 | 412.5 | 471.8 | 29.8 | 56.55 | 59.53 | 1829.21 |
| | | 24 ton/ha | 53.57 | 684.53 | 60.98 | 0.0 | 825.0 | 471.8 | 29.8 | 56.55 | 59.53 | 2241.71 |
| | | 36 ton/ha | 53.57 | 684.53 | 60.98 | 0.0 | 1237.5 | 471.8 | 29.8 | 56.55 | 59.53 | 2654.21 |
| | Mulch | Non- | 53.57 | 684.53 | 60.98 | 150 | 0.0 | 471.8 | 29.8 | 56.55 | 59.53 | 1566.71 |
| | | 12 ton/ha | 53.57 | 684.53 | 60.98 | 150 | 412.5 | 471.8 | 29.8 | 56.55 | 59.53 | 1979.21 |
| | | 24 ton/ha | 53.57 | 684.53 | 60.98 | 150 | 825.0 | 471.8 | 29.8 | 56.55 | 59.53 | 2391.71 |
| | | 36 ton/ha | 53.57 | 684.53 | 60.98 | 150 | 1237.5 | 471.8 | 29.8 | 56.55 | 59.53 | 2804.21 |

* = 4000 m³/ha, **Euro= 8.0 L.E.

Table (46): Profit of potato production (Euro/ha) under different compost rates, mulch and water regimes

| Water regime | Mulch | Compost | Total costs | Total tuber yield (ton/ha) | Profit for local consumption in Egypt | Profit for exportation |
|---|---|---|---|---|---|---|
| 100 % of $ET_c$* | Non-mulch | Non-compost | 1457.36 | 16.05 | 3611.93 | 6421.2 |
| | | 12 ton/ha | 1869.86 | 19.33 | 4349.93 | 7733.2 |
| | | 24 ton/ha | 2282.36 | 22.17 | 4987.58 | 8866.8 |
| | | 36 ton/ha | 2694.86 | 23.94 | 5387.18 | 9577.2 |
| | Mulch | Non-compost | 1607.36 | 14.72 | 3312.68 | 5889.2 |
| | | 12 ton/ha | 2019.86 | 17.97 | 4042.58 | 7186.8 |
| | | 24 ton/ha | 2432.36 | 20.06 | 4512.83 | 8022.8 |
| | | 36 ton/ha | 2844.86 | 17.67 | 3975.08 | 7066.8 |
| 80 % of $ET_c$ | Non-mulch | Non-compost | 1437.03 | 19.28 | 4338.00 | 7712.0 |
| | | 12 ton/ha | 1849.53 | 22.94 | 5162.18 | 9177.2 |
| | | 24 ton/ha | 2262.03 | 26.89 | 6050.25 | 10756.0 |
| | | 36 ton/ha | 2674.53 | 29.56 | 6650.33 | 11822.8 |
| | Mulch | Non-compost | 1587.03 | 20.17 | 4537.58 | 8066.8 |
| | | 12 ton/ha | 1999.53 | 23.95 | 5388.08 | 9578.8 |
| | | 24 ton/ha | 2412.03 | 27.94 | 6287.18 | 11177.2 |
| | | 36 ton/ha | 2824.53 | 30.28 | 6812.33 | 12110.8 |
| 60 % of $ET_c$ | Non-mulch | Non-compost | 1416.71 | 15.56 | 3500.33 | 6222.8 |
| | | 12 ton/ha | 1829.21 | 26.33 | 5924.93 | 10533.2 |
| | | 24 ton/ha | 2241.71 | 30.11 | 6774.08 | 12042.8 |
| | | 36 ton/ha | 2654.21 | 31.72 | 7137.68 | 12689.2 |
| | Mulch | Non-compost | 1566.71 | 17.78 | 3999.83 | 7110.8 |
| | | 12 ton/ha | 1979.21 | 27.61 | 6212.93 | 11045.2 |
| | | 24 ton/ha | 2391.71 | 30.72 | 6912.00 | 12288.0 |
| | | 36 ton/ha | 2804.21 | 32.67 | 7350.08 | 13066.8 |

* = 4000 $m^3$/ha, **Euro= 8.0 L.E.

**Table (47): Effect of compost and mulch on net profit (Euro**/ha) for local consumption in Egypt under different water regimes**

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 2,154.57 | 1,705.32 | **1929.94** |
| | 12 ton/ha | 2,480.07 | 2,022.72 | **2251.39** |
| | 24 ton/ha | 2,705.22 | 2,080.47 | **2392.84** |
| | 36 ton/ha | 2,692.32 | 1,130.22 | **1911.27** |
| | Mean | **2508.04** | **1734.68** | **2121.36** |
| 80 % of $ET_c$ | Non-compost | 2,900.97 | 2,950.54 | **2925.76** |
| | 12 ton/ha | 3,312.64 | 3,388.54 | **3350.59** |
| | 24 ton/ha | 3,788.22 | 3,875.14 | **3831.68** |
| | 36 ton/ha | 3,975.79 | 3,987.79 | **3981.79** |
| | Mean | **3494.41** | **3550.51** | **3522.46** |
| 60 % of $ET_c$ | Non-compost | 2,083.62 | 2,433.12 | **2258.37** |
| | 12 ton/ha | 4,095.72 | 4,233.72 | **4164.72** |
| | 24 ton/ha | 4,532.37 | 4,520.29 | **4526.33** |
| | 36 ton/ha | 4,483.47 | 4,545.87 | **4514.67** |
| | Mean | **3798.79** | **3933.25** | **3866.02** |
| | Mean | **3267.08** | **3072.81** | |
| Grand mean | | | | **3169.95** |

**Mean of compost**

| Compost | Water regime | | | Mean |
|---|---|---|---|---|
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| **Non-compost** | 1929.94 | 2925.76 | 2258.37 | **2371.36** |
| **12 ton/ha** | 2251.39 | 3350.59 | 4164.72 | **3255.57** |
| **24 ton/ha** | 2392.84 | 3831.68 | 4526.33 | **3583.62** |
| **36 ton/ha** | 1911.27 | 3981.79 | 4514.67 | **3469.24** |
| **Mean** | **2121.36** | **3,522.46** | **3866.02** | **3169.95** |

* = 4000 m³/ha, **Euro= 8.0 L.E.

**Table (48): Effect of compost and mulch on net profit (Euro**/ha) for exportation under different water regimes**

| Water regime | Compost | Mulch | | Mean |
|---|---|---|---|---|
| | | Non-mulch | Mulch | |
| 100 % of $ET_c$* | Non-compost | 4,963.84 | 4,281.84 | **4622.84** |
| | 12 ton/ha | 5,863.34 | 5,166.94 | **5515.14** |
| | 24 ton/ha | 6,584.44 | 5,590.44 | **6087.44** |
| | 36 ton/ha | 6,882.34 | 4,221.94 | **5552.14** |
| | Mean | **6073.49** | **4815.29** | **5444.39** |
| 80 % of $ET_c$ | Non-compost | 6,274.97 | 6,479.77 | **6377.37** |
| | 12 ton/ha | 7,327.67 | 7,579.27 | **7453.47** |
| | 24 ton/ha | 8,493.97 | 8,765.17 | **8629.57** |
| | 36 ton/ha | 9,148.27 | 9,286.27 | **9217.27** |
| | Mean | **7811.22** | **8027.62** | **7919.42** |
| 60 % of $ET_c$ | Non-compost | 4,806.09 | 5,544.09 | **5175.09** |
| | 12 ton/ha | 8,703.99 | 9,065.99 | **8884.99** |
| | 24 ton/ha | 9,801.09 | 9,896.29 | **9848.69** |
| | 36 ton/ha | 10,034.99 | 10,262.59 | **10148.79** |
| | Mean | **8336.54** | **8692.24** | **8514.39** |
| | Mean | **7407.08** | **7178.38** | |
| **Grand mean** | | | | **7292.73** |

**Mean of compost**

| Compost | Water regime | | | Mean |
|---|---|---|---|---|
| | 100 % of $ET_c$ | 80 % of $ET_c$ | 60 % of $ET_c$ | |
| Non-compost | 4622.84 | 6377.37 | 5175.09 | 5391.77 |
| 12 ton/ha | 5515.14 | 7453.47 | 8884.99 | 7284.53 |
| 24 ton/ha | 6087.44 | 8629.57 | 9848.69 | 8188.57 |
| 36 ton/ha | 5552.14 | 9217.27 | 10148.79 | 8306.07 |
| Mean | 5444.39125 | 7,919.42 | 8514.39 | 7292.73 |

* = 4000 m³/ha, **Euro= 8.0 L.E.

### *5.5.1. <u>General effect of individual factors on net profit (net income)</u>*

Incorporating compost in the soil significantly increased net profit (NP)(net income) of local consumption and exportation for potato crop compared to the soil that didn't receive compost, except for Incorporating compost at 36 ton $ha^{-1}$where the net profit decreased for local consumption and insignificantly increased for exportation. In other words, increments in NP for potato crop, which was treated with compost compared to that didn't receive compost, were 38.5, 52.8 and 47.8 % for local consumption and 35.6, 52.6 and 54.8 % for exportation by applying 12, 24 and 36 ton $ha^{-1}$of compost, respectively. The maximum NP value for local consumption and the best one for exportation were achieved by applying 24 ton $ha^{-1}$ of compost (fig. 74-77).

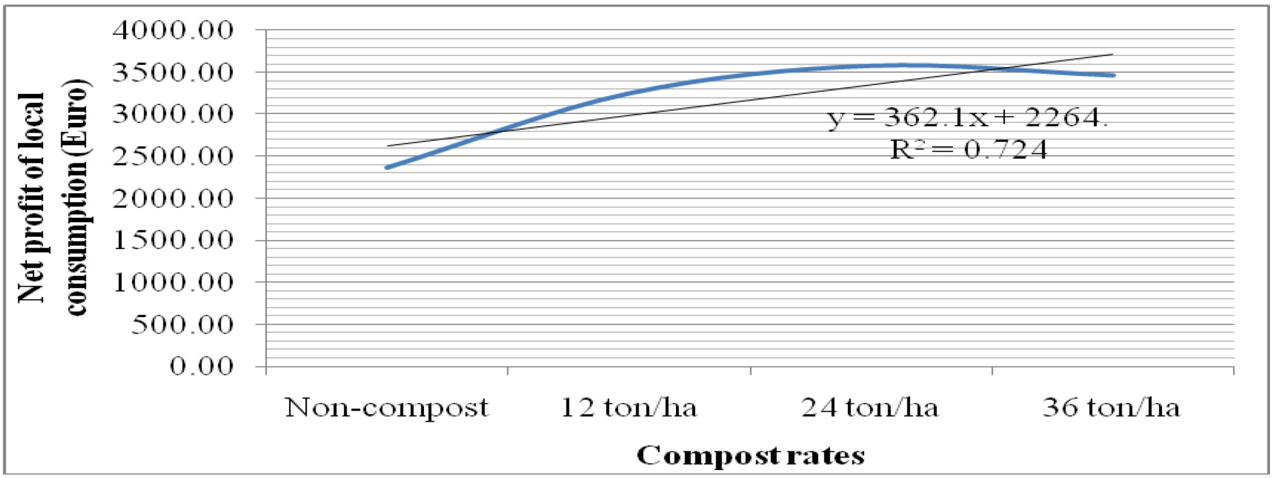


**Fig.(74): Effect of compost rates on net profit for local potato consumption in Egypt**

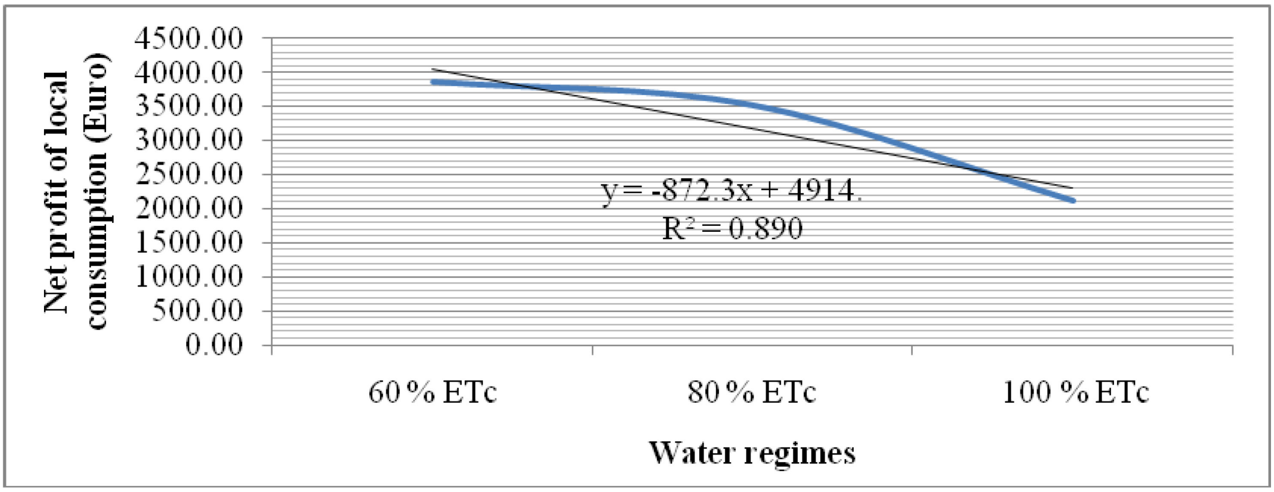


**Fig.(75): Effect of water regimes on net profit for local potato consumption in Egypt**

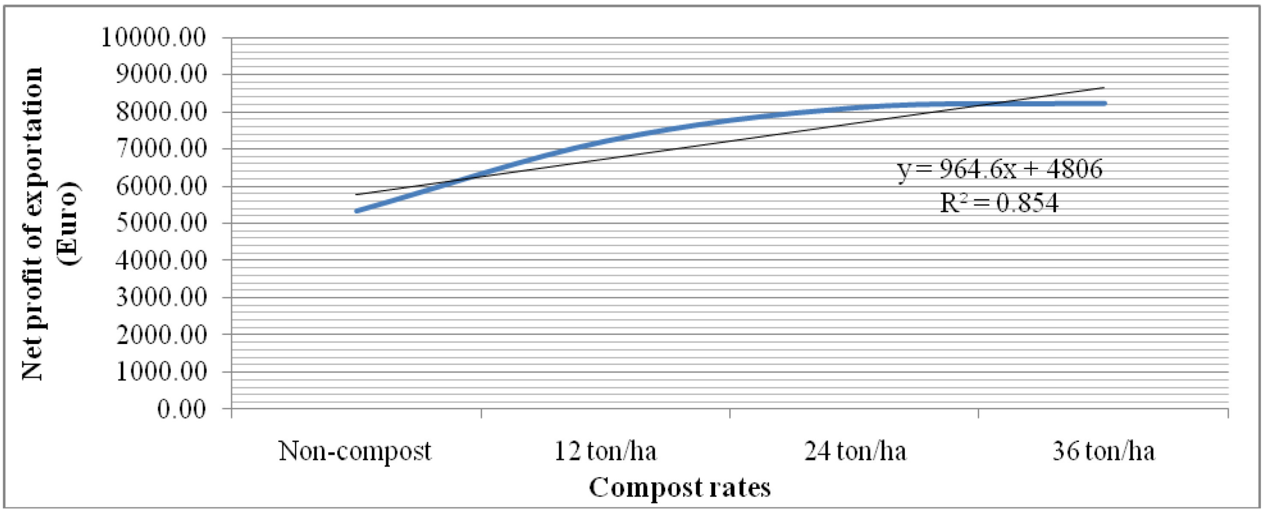


**Fig.(76): Effect of compost rates on net profit for exportation**

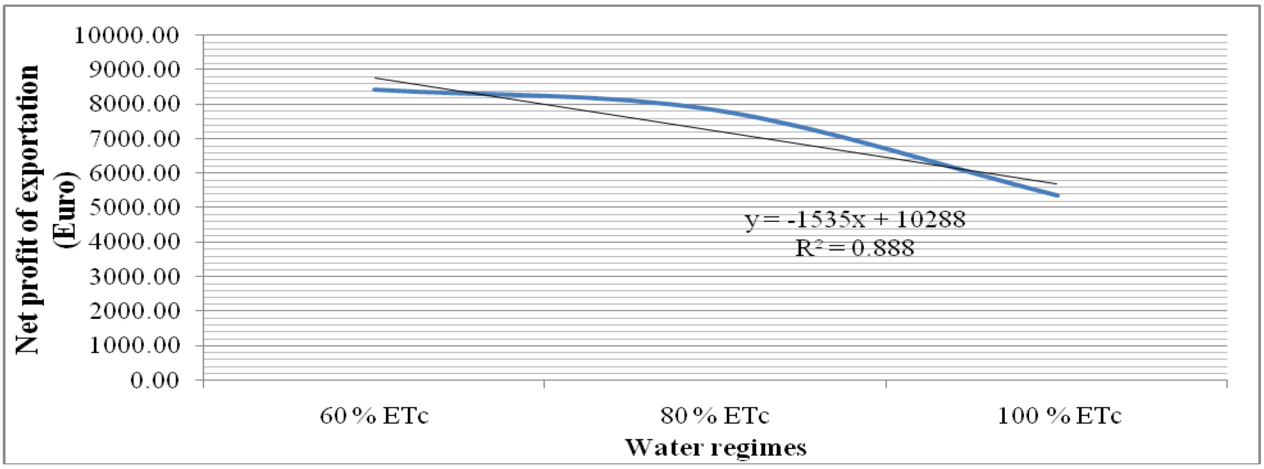


**Fig.(77): Effect of water regimes on net profit for exportation**

In contrast, it could be detected that in general soil mulching slightly decreased the values of NP. Comparing NP for potato in the mulched soil to that in the non-mulched one, NP for potato of the former were 98.6 and 99.0 % of the latter for local consumption and exportation, sequentially.

Concerning the effect of water regimes on NP for potato, data in hand reveal that increasing applied water to the soil considerably decreased NP for potato. Comprehensively, decrements in NP for potato for local consumption were 9.0 and 46.0 % of water regime of (60 % of $ET_c$ ) for water regimes of (80 and 100 % of $ET_c$), respectively. Relevant values for exportation were 7.0 and 36.4 %.

***5.5.1.1.<u>Effect of the triple interaction among water regime, mulch and compost on net profit (net income):</u>***

It could be noticed that the triple interaction among water regimes, mulch and compost rates resulted in considerable effects on NP for potato. In other words, the decrement in applied water with increasing applied compost rates increased NP for potato in mulched and none mulched soils **(**tables 46- 48).

The maximum NP values (4,545.87 and 10,262.59 Euro/ha) for potato were recorded by the combination of (60 % its water regime + with soil mulching + applying compost rate of 36 ton $ha^{-1}$). But NP values (4,520.29 and 9,896.29 Euro/ha) were achieved by the combination of (60 % of $ET_c$ water regime + with soil mulching + applying compost rate at 24 ton $ha^{-1}$) for local consumption and exportation, in sequence. Since the differences between the aforementioned maximum value and the best one were only 25.58 Euro/ha for local consumption and 366.3 Euro/ha for the exportation. On the other hand, the minimum

NP values (1,130.22 and 4,221.94 Euro/ha) for potato were recorded by the combination of (100 % of $ET_c$ water regime + with soil mulching + applying compost rate at 36 ton ha$^{-1}$) for local consumption and exportation, respectively (Fig. 78-79).

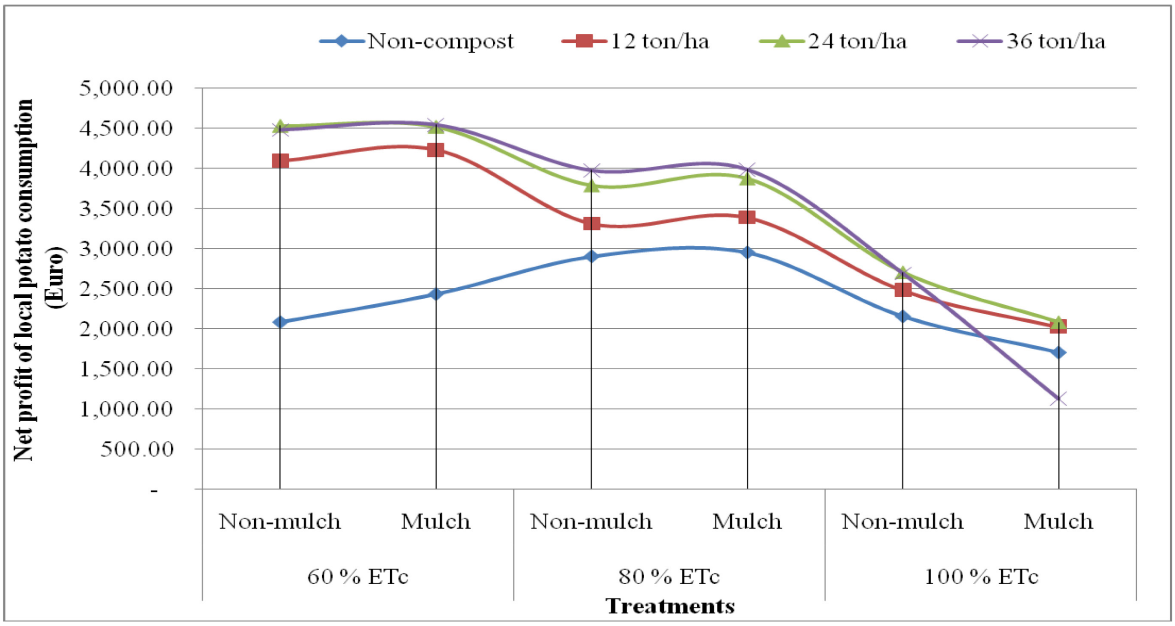


**Fig.(78): Effect of the interaction among water regime, mulch and compost on net profit for local potato consumption**

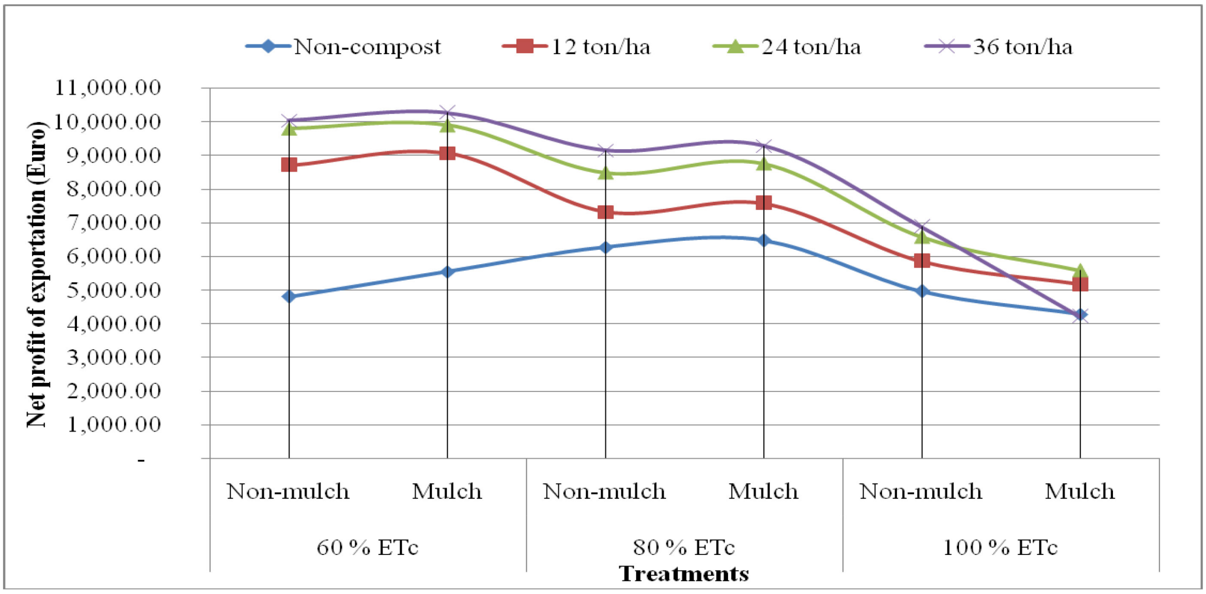


**Fig.(79): Effect of the interaction among water regime, mulch and compost on net profit for potato exportation**

## 6. DISCUSSION

Rapid growth of the population and food security are the main global problems. Such problems put supplemental pressure for agricultural development in Egypt. The growing urban sprawl on the alluvial land of the River Nile and delta has encouraged governmental and private sectors for agricultural horizontal expansion in the Western Desert which is characterized by sandy soil (Abdel Kawy and Abou El-Magd, 2012).

Sandy soils have two major problems: low fertility and inadequate water retention. Wind erosion, drought and loss of irrigation water and plant nutrients are expected (Balba, 1989). Under such severe conditions desired yield levels are difficult to achieve. However, they could be as productive as fertile soil, if the right soil water management is applied. The obvious way to raise soil moisture retention in such soils is frequent water application and/ or using soil conditioner i.e. compost. The application of organic material to sandy soils (20 - 40 ton $ha^{-1}$) has quite a similar effect to that of clay with some exceptions that organic matter is quickly decomposed, so it is difficult to maintain more than 1 or 2 percent without heavy and seasonal manure. The use of soil conditioner has importance to avail suitable environment for crop cultivation (El-Hady et al., 2010).

It is necessary to get maximum yield in agriculture by using available water in order to get maximum profit per unit area. Therefore, the right amount of water needed for the plants must be determined and supplied. Furthermore, it is essential to develop the most suitable irrigation schedule to get optimum plant yield for different ecological regions as plant water consumption depends mostly on plant growth, soil and climatic conditions (Ertek et al., 2002).

In arid and semiarid regions, water is a limiting factor in the expansion of cultivated area. As irrigation water is a costly input in crop production in the Western Desert, where the only source of water is the underground water, efficient use of it should be achieved through judicious water management practices.

In this investigation, the proper soil and water management (water regime, soil mulching and incorporating compost in the soil) could increase soil moisture retention, improve soil properties and also achieve the best total potato tuber yield, water economy, water use efficiency and net profit under Western Desert conditions in Egypt.

Taking into consideration that all parameters of this investigation are presented as the general means for experimental data using split-split plot design where statistically the effect of the triple interactions among treatments was the most important, obtained results are explained as follows:-

***Effect of applying compost:***

Incorporating compost at three rates (12, 24, 36 ton $ha^{-1}$) compared to that of soil which didn't receive compost led to beneficial effects on soil physical and hydrophysical properties. Compost incorporated in the soil decreased its bulk density, drainable pores, infiltration rate, hydraulic conductivity and mean diameter of soil pores (Sangakkara, 1998; Ebertseder and Gutser, 2001; Weinfurtner, 2001; Sharma and Campbell, 2003; Thompson et al., 2008; El-Hady et al., 2010). However compost led to an increase in soil total porosity, void ratio, water holding pores and hence its moisture retention (total holding capacity, field capacity and wilting percentages) (Magdoff, 1992; Pagliai et al., 2004; Lynch et al., 2005; Savabi et al., 2005; Mylavarapu and Zinati, 2009).The results led us to that compost is one of the most important soil conditioner, it plays a vital role in improving soil properties and sustaining nutrient status.

Compost improved the water holding capacity of sandy soil and the ability of the soil to retain water due to its effect on pore size distribution towards of tine ones, i.e., water holding pores. Although applying organic materials increased the water held both at the wilting percentage and at field capacity, the latter was usually increased more. Thus the total available water in the soil was usually increased and this increase was at tensions at which plants can more easily withdraw water (Baker, 1984; Sommerfeldt and Chang, 1985; Hernando, et al., 1989; Tester, 1990; Schnitzer, 1991; Reicosky et al. 1995; Tzeng et al. 1996; Aleson et al., 1997 and Feng et al., 1998; Foley and Cooperband, 2002) ).

Organic materials developed the dynamic soil water characteristics, i.e. decreasing the downward movement of water through infiltration and the upward movement of it via evaporation (Pandey and Shukla, 2006). Tiarks et al., 1974; Schnitzer, 199l; Sabrah, 1994 and Sabrah et al., 1995 reported that Organic materials application reduced the hydraulic conductivity of disturbed soils.

Moreover, increasing the rates of applied compost considerably increased plant height or number of branches per plant and consequently increased its average potato tuber weight, average yield per plant, number of potato tubers per plant and total tuber yield (Acharya and Kapur, 2001; Carter et al., 2004; Abou Hussein ,2005; Hachicha et al.,2006; Makhan and Khurana, 2007). The positive effect of compost on plant growth, yield and its components may be due to that applying compost improved soil physical and hydrophysical properties as above mention (Hillel, 1980; Sabrah et al., 1995). Also, applying compost to the soil improved soil fertility and increases cation exchange capacity of soils, thus allowing increased availability of certain nutrients such calcium, magnesium and phosphorus (Brady 1974, Seyedbagheri, 1999, Abou-Hussein, 2001)

Referring to nutrient percentages in the plant, increasing the rate of applied compost to be 12, 24, 36 ton $ha^{-1}$compared to the non treated soil with compost increased nitrogen (N), phosphorus (P) and potassium (K) percentage in the plant (Pieruccetti et al., 2008; Thompson et al., 2008; Sodhi et al., 2009; Lalljee, 2006). This effect might be due to that applying compost led to increase in the organic matter in the soil which gave enough nitrogen to microorganisms living in the soil to convert the nutrients from organic form to mineral one to make nutrients available for plant. Moreover, the organic acids which result from organic decompositions dissolve some soil minerals like phosphorus to ease plant uptake (Wahba and Darwish, 2008; Abdel-Motaal, 2005; Sharma and Campbell, 2003 ; Ouattara, 1994). Also, nitrogen, phosphorus and potassium fertilizers use were more efficient by increasing the rate of applied compost (Kulakovskya and Brysovskii, 1984).

In addition, the more the amount of applied compost was, the higher were in water consumption, crop coefficient, water economy and water use efficiency of the potato plant. This may be due to that incorporating compost in the soil caused an increase in soil moisture retention and nutrient availability and hence increase in growth parameters for potato plant, yield components and consequently the excess in total tuber yield.

As the result of the above mentioned net profits (NP)(net income) of local consumption and exportation for potato crop were significantly increased compared to the soil that didn't receive compost except in incorporating compost at 36 ton $ha^{-1}$, net profit was decreased for local consumption and insignificantly increased for exportation. Compost rate of 24 ton $ha^{-1}$ achieved the highest value for local potato consumption and the best value for exportation.

***Effect of soil mulching:***

Mulching the soil with dried sugar cane wastes generally reduced soil bulk density, hydraulic conductivity and infiltration rate and slightly increased total porosity, void ratio and hence increased soil moisture retention (total holding capacity, field capacity and wilting percentages) (Deng et al., 2006). Tindall et al. (1991) and Materechera (2009) determined that there were significant improvements in soil aggregate properties in the amended soil over the control, Edwards et al. (2000b) and Chakraborty et al. (2008) showed that mulching is one of the important agronomic practices in conserving the soil moisture and modifying the soil physical environment.

Regarding potato growth parameters, i.e. plant height and number of branches per plant, they increased in mulched soil compared to non-mulched one. With respect to the effect of soil mulching on yield and its components, soil mulching significantly increased average potato tuber weight, this result could be in agreement with Döring et al., 2003. While there was a slight decrease in the average yield per plant, number of potato tubers per plant and total tuber yield (Ghuman and Lala, 1983; Döring et al., 2005).

Comparing the nutrient percentages of the potato plant in mulched soil to that of the potato plant in non-mulched one, it could be detected that generally soil mulching increased the values of nitrogen (N), phosphorus (P) and potassium (K) percentages in potato plant. Kar and Kumar (2007) stated that application of straw mulch significantly increased the available phosphorus and potassium in the soil. Romic et al. (2003) and Rahman et al. (2005) noticed that soil mulching reduced the leaching of nitrate fertilizers while increased nitrogen uptake and apparent nitrogen recovery of applied nitrogen fertilizer.

Soil mulching slightly led to an increase in the total water consumptive use for potato under all treatments of applying compost and water regimes. Wang et al. (2001) and Yan Hou et al. (2010) found that mulch reduced irrigation water required and evapotranspiration. Deng et al. (2006) mentioned that mulching with crop residues can improve water use efficiency by 10–20% through reducing soil evaporation and increasing plant transpiration.

As well, mulching the soil with dried sugar cane wastes insignificantly increased water economy but slightly reduced the values of water use efficiency and net profit. It might be detected that because the potato plant can be grown only at the winter season in Kharga Oasis in the Western Desert, so soil mulching alone had no effect on water use efficiency, although had varying effects with compost rates under different water regimes, but it may be noticed that soil mulching has a great effect on the crops through the summer season as climatic conditions are more arid (Midmore et al., 1986; Deng et al., 2006).

***Effect of water regimes:***

Regarding applying three water regimes to the soil, i.e. 100 %, 80 % and 60 % of $ET_{crop}$, increasing applied water to the soil insignificantly decreased its bulk density, its drainable pores, Water holding pores, infiltration rate, and field capacity. On the other hand, increasing applied water to the soil insignificantly increased its void ratio, total porosity, hydraulic conductivity, diameter of soil pores, and total holding capacity of the soil.

Concerning the effect of water regime solely on none mulched soil that didn't receive compost, it could be indicated that all crop parameters increased with increasing the irrigation water from 60 % of $ET_c$ to 80% of $ET_c$ and then reduced by 100% of $ET_c$ (Zhong Yuan et al., 2003), this may be determined by the excess of applied water above potato plant requirements which caused a shortage of plant growth and therefore caused the reduction in potato yield components.

On the contrary, with regard to the general effect of water regime, it could be noticed that plant height or number of branches per plant gradually decreased by increasing the amounts of irrigation water from 60 % of the $ET_c$ to 100 % of the $ET_c$, also, the increase in the irrigation water significantly led to decrease in nitrogen, phosphorus and potassium percentages. This might be due to that the higher water level had a negative effect on soil aeration and increased nutrient losses with reduction condition.

Both average potato tuber weight and average yield per plant gradually decreased with increasing applied irrigation water from 60 % of the $ET_c$ to 100% of the $ET_c$ (Hassanpanah and Benam, 2007). In contrast, increasing applied water irrigation level from 60 % of $ET_c$ to 80 % of $ET_c$ increased number of potato tubers per plant then increasing water level to 100 % of $ET_c$ decreased it. In general, total tuber yield increased with decreasing water irrigation level. (Foeti et al., 1995; Stark and McCann, 1992; Eid et al., 1987).

Total water consumption for potato increased with increasing water irrigation level (El-Naggar, 1997).

On the other hand, using irrigation treatments solely, 80 % of $ET_c$ gave the best water regime (Kumar et al., 2007). In details, the increasing applied water from 60 to 80 % of $ET_c$ led to an increase in total tuber yield (Hassanpanah and Benam, 2007), $K_c$, water economy, water use efficiency and net profit but increasing applied water by 100 $ET_c$ caused decrement.

However, as a general effect of studied treatments, water economy, water use efficiency and net profit significantly decreased with increasing the amounts of irrigation water from 60 % of the $ET_c$ to 100% of the $ET_c$.

***Effect of interactions among the studied factors:***

Interactions among the three studied factors; water regime, soil mulching and applying compost are discussed in the following:-

**Regarding the interaction between water regime and mulch,** the highest plants and number of branches per plant were achieved under 60 % of $ET_c$ of water regime in mulched soil while the shortest plants having the lowest number of branches were obtained under 100 % of $ET_c$ of water regime in the same mulched soil. This may be caused by reduced evaporation from the soil surface due to soil mulching and saved water in root zone for plants, thus the excess of water above potato plant needed attributed to the reduction in soil aeration, root respiration and plant synthesis, Wang et al. 2001 mentioned that mulching reduced soil evaporation by up to 50% and Hou et al. (2010) found that mulch reduced irrigation water required and evapotranspiration.

Moreover, the highest values of nitrogen, phosphorus and potassium percentages were determined in the plant tissue from (60 % of $ET_c$ of water regime + soil mulching) interaction. On the contrary, the greatest decrements in N, P and K percentages were found by (100 % of $ET_c$ of water regime + soil mulching). This may be due to the interaction, for excessive irrigation water + soil mulching which caused nitrate losses, thus leading to shortage of plant growth, conventionally reduction in nitrogen, phosphorus and potassium percentages in the potato plant.

It could be observed that there were significant effects of this interaction on potato tuber weight and yield per plant. The lowest values for potato tuber weight and yield per plant were obtained from 100 % of the $ET_c$ water regime in mulched soil. Similar results were reported by Kar and Kumar (2007). As aforementioned this may be due to the soil mulching and the excess of applied water above potato plant needs**,** Therefore, the highest value of total potato tuber yield (27.2 ton $ha^{-1}$) was achieved under 60 % of the $ET_c$ water regime in mulched soil while the lowest one (17.6 ton $ha^{-1}$) was recorded by 100 % of the $ET_c$

water regime in mulched soil. This may be due to the interaction for excessive irrigation water + soil mulching caused shortage of plant growth, reduction in potato yield components and hence decrease in total tuber yield (Shrivastava et al., 1994).

It could be determined that there were significant effects of soil mulching on water economy and water use efficiency (Deng et al., 2006). In detail, decreasing water regimes with mulch increased water economy and water use efficiency (Kar and Kumar, 2007; Yan Hou et al., 2010).

**With respect to the effect interaction between compost and mulch,** it was of a considerable importance for soil properties (Edwards et al., 2000a), potato growth parameters, nutrient percentages, potato tuber yield and its components, water economy and water use efficiency. Relating to potato tuber weight as a quality indicator, the differences in potato tuber weight were much less between incorporating compost rate at 24 and 36 ton $ha^{-1}$ in mulched soil. This may lead us to the conclusion that applied compost rate at 24, ton $ha^{-1}$ in mulched soil, has the best double interaction between compost and mulch.

It could be determined that the highest value of total tuber yield (26.87 ton $ha^{-1}$) was attained due to applying compost rates at 36 ton $ha^{-1}$in none mulched soil. However, the lowest value (16.96 ton $ha^{-1}$) was obtained in the same soil that was not treated with compost. Similar results have been found by Mc Burine and Mitchell (1993), Gent et al. (1998) and Gingerich (2000).

Moreover, the highest values of water economy (9.48 kg $m^{-3}$) and water use efficiency (10.75 kg $m^{-3}$) were attained by incorporating 36 ton $ha^{-1}$ of compost in non mulched soil. Conversely, the lowest values were obtained from the same soil that didn't receive compost.

**As regards the effect of the interaction between water regime and compost,** Obviously the double interaction among water regimes and compost rates resulted in significant differences on growth parameters, nutrient percentages, yield and its components, water economy and water use efficiency.

The highest plants and its number of branches were obtained by the combination between 60 % of $ET_c$ water regime and applying compost rate of 36 ton $ha^{-1}$. On the other hand, the shortest plants and its number of branches were recorded without compost and applying compost rate of 36 ton $ha^{-1}$ under 100 % of $ET_c$ of water regime in mulched soil. It may be this due to the excess of applied water and applied compost rate more than potato plant needed attributed to the increase in reduction condition and the decrease in soil aeration, root respiration and plant synthesis and hence the shortage of plant and the reduction of the number of branches.

Applying 36 ton $ha^{-1}$compost rate under 60 % of the $ET_c$ water regime gave the highest value of total tuber yield ( 32.2 ton $ha^{-1}$) while the interaction between none compost and 100 % of the $ET_c$ water regime recorded the lowest value of total tuber yield ( 15.4 ton $ha^{-1}$).

Regarding water economy and water use efficiency, applying 36 ton $ha^{-1}$compost rate under 60 % of the $ET_c$ attained the highest values of water economy (13.34 kg $m^{-3}$) and water use efficiency (15.03 kg $m^{-3}$). Other than the difference between the interaction (36 ton $ha^{-1}$compost rate under 60 % of the $ET_c$) and interaction (24 ton $ha^{-1}$compost rate under 60 % of the $ET_c$), was insignificant, thus it might be recognized that interaction (24 ton $ha^{-1}$compost rate under 60 % of the $ET_c$) achieved the best value (14.9 kg $m^{-3}$), this depends on the net profit (total costs – profits).

**Regarding effect of the triple interactions among water regime, mulch and compost**, under split-split plot design of this field experiment, the triple interactions among the studied treatments were the most important interactions. Obtained results indicated that the triple interaction among water regimes under drip irrigation technology , mulch and compost rates resulted in significant effects on growth parameters, nutrient percentages, yield and its components, water economy, water use efficiency and net profit (net income).

The highest value of total tuber yield (32.6 ton $ha^{-1}$) was achieved by the combination between 60 % of the $ET_c$ water regime, soil mulching and applying compost rate of 36 ton $ha^{-1}$. In contrast, the lowest value of total tuber yield (14.7 ton $ha^{-1}$) was recorded without applying compost in mulched soil under 100 % of the $ET_c$ water regime (Acharya and Kapur, 2001).

About water economy and water use efficiency, the highest values for water economy (13.62 kg $m^{-3}$) and water use efficiency ( 15.06 kg $m^{-3}$) were achieved by the combination between 60 % of the $ET_c$, soil mulching and applying compost rate of 36 ton $ha^{-1}$. On the other hand, it could be observed for water use efficiency that the difference between the combination between (60 % of the $ET_c$+ soil mulching + applying compost rate of 36 ton $ha^{-1}$) and the combination between (60 % of the $ET_c$, + soil mulching + applying compost rate at 24 ton $ha^{-1}$), was insignificant. Therefore, it may be detected that the last combination could be the best value according to the net income (Outputs – Inputs).

Referring to net profit (net income) for potato, the decrement in applied water with increasing applied compost rates considerably increased NP for potato in mulched and none mulched soils. The maximum NP values (4,545.87 and 10,262.59 Euro/ha) for potato were recorded by the combination between 60 % of $ET_c$ water regime + with soil mulching + applying compost rate at 36 ton $ha^{-1}$, but the best NP values (4,520.29 and 9,896.29 Euro/ha) were achieved with the combination between (60 % of $ET_c$ water regime + with soil mulching + applying compost rate at 24 ton $ha^{-1}$) for local consumption and exportation, respectively, since the increments in the aforementioned maximum value and the best one were only 25.58 Euro/ha for local consumption and 366.3 Euro/ha for the exportation, at the same time it saves 12 ton compost $ha^{-1}$that can be planting a new area (about 1/2 ha).

There were four important situations for the triple interactions, it might be mentioned the following:-

-With respect of the triple interaction between (drip water regimes+ none soil mulching+ none compost) it could be observed that the triple interaction among (80% of $ET_c$ water regimes+ none soil mulching+ none compost) gave the best water regime ($K_c$ =0.77) (Kumar et al., 2007).

- Regarding the triple interaction drip water regimes + soil mulching+ none compost, it may be observed that the interaction between 80 % of $ET_c$ water regime + soil mulching+ none compost was the best treatment ($K_c$ =0.79) (Shrivastava et al., 1994).

-Referring to the triple interactions drip water regimes + none soil mulching+ applied compost rates, it might be noticed that the treatment of 60 % of $ET_c$ water regime + none soil mulching +compost rate of 36 ton $ha^{-1}$ gave the highest values of studied parameters, but the treatment of 60 % of $ET_c$ water regime + none mulching +compost rate of 24 ton $ha^{-1}$ ($K_c$ =0.83) and the treatment of 80 % of $ET_c$ water regime + none mulching +compost rate of 12 ton $ha^{-1}$($K_c$ =0.82) achieved the best values.

-Concerning the triple interactions drip water regimes + soil mulching+ applied compost rates, it could be detected that the highest values were obtained by the combination among 60 % of $ET_c$ water regime + soil mulching +compost rate of 36 ton $ha^{-1}$ ($K_c$ =0.90), however the combination among 60 % of $ET_c$ water regime + soil mulching +compost rate at 24 ton $ha^{-1}$ ($K_c$ =0.86) achieved the best values of potato tuber yield and its components, water economy, water use efficiency and net profit (net income) for local consumption and exportation. Since the differences between the aforementioned maximum value of net profit and the best one were insignificant for local consumption and the exportation.

## 7. CONCLUSION

Under the arid condition of Kharga Oasis in the Western Desert of Egypt, the present investigation was carried out; studied factors were water regimes (60, 80 and 100 % of $ET_{crop}$) using drip irrigation system, soil mulching (with raw sugar cane wastes) and compost (composted sugar cane wastes) (0, 12, 24 and 36 ton ha$^{-1}$), indicator plant was potato.

The study included the effect of the aforementioned factors on plant growth, nutrient concentration in the plant, yield and yield components on one hand and water economy, water use efficiency, fertilizer use efficiencies and crop coefficients on the other hand. The improvement in soil properties and net profit (Net income = Total income for output - Total costs for Inputs).

Regarding the effect of the studied factors on plant growth, nutrient concentration in the plant, yield and yield components which include plant height, number of branches per plant, nitrogen, phosphorus and potassium concentration in the plants, potato tuber weight, tuber yield per plant and total tuber yield, the highest values could be achieved by the combination of (60 % of $ET_c$ water regime + soil mulching + incorporating 36 ton ha$^{-1}$ of compost).

With respect to the influence of water economy, water use efficiency that relate obtained yield in kilograms with either applied or consumed water in m$^{-3}$ by the plants and nitrogen, phosphorus and potassium use efficiencies that relate obtained yield in kilograms with added fertilizers in kilograms, a conclusion was drawn that incorporating 36 ton ha$^{-1}$ of compost in mulched soil irrigated with 60 % of $ET_c$ gave the highest values.

Applying economic analysis arrived to the conclusion that the maximum net profit for local consumption of potato or exportation was obtained due to incorporating 36 ton ha$^{-1}$ of compost in mulched soil irrigated with 60 % of $ET_c$. Since the differences between incorporating 36 and 24 ton ha$^{-1}$ of compost was insignificant, at the same time it saves 12 ton of compost that can be added for new area ( ½ ha). Therefore incorporating 24 ton ha$^{-1}$ of compost in mulched soil irrigated with 60 % of $ET_c$ could be considered the best.

Besides the improvement in hydrophysical properties of soil that included soil bulk density, void ratio, soil porosity and pore size distribution, available water in the soil, infiltration rate, hydraulic conductivity and mean diameter of soil pores confirmed the aforementioned conclusion.

Some equations related among the parameters under study were achieved according to the prevailing conditions in Western Desert, Egypt, which may be applied in other locations that have similar conditions of water, soil and climate. Some equations are shown in the following:-

**7.1. Effect of compost rates and water regime using soil mulching on total tuber yield as follows:-**

7.1.1. $y = 3.4431\ x_1 + 14.951$

$R^2 = 0.9231$

Where y: Total tuber yield (ton/ha), $x_1$: Compost rate (ton/ha) and $R^2$: coefficient of determination (linear regression).

7.1.2. $y = -3.7865\ x_2 + 31.132$

$R^2 = 0.8863$

Where y: Total tuber yield (ton/ha), $x_2$: Water regime (% of $ET_c$) and $R^2$: coefficient of determination (linear regression).

**7.2. Effect of compost rates and water regime on water economy using soil mulching as follows:-**

7.2.1. $y = 1.2119\ x_1 + 4.8671$

$R^2 = 0.9181$

Where y: Water economy (kg $m^{-3}$), $x_1$: Compost rate (ton/ha) and $R^2$: coefficient of determination (linear regression).

7.2.2. $y = -3.1633\ x_2 + 14.224$

$R^2 = 0.9999$

Where y: Water economy (kg $m^{-3}$), $x_2$: Water regime (% of $ET_c$) and $R^2$: coefficient of determination (linear regression).

**7.3. Effect of compost and water regime on water use efficiency using soil mulching as follows:-**

7.3.1. $y = 0.977\ x_1 + 6.9595$

$R^2 = 0.8416$

Where y: Water use efficiency (kg $m^{-3}$), $x_1$: Compost rate (ton/ha) and $R^2$: coefficient of determination (linear regression).

7.3.2. $y = -3.8367\ x_2 + 17.077$

$R^2 = 0.998$

Where y: Water use efficiency kg $m^{-3}$, $x_2$: Water regime (% of $ET_c$) and $R^2$: coefficient of determination (linear regression).

### 7.4. Effect of compost and water regime on net profit for local potato consumption in Egypt using soil mulching as follows:-

7.4.1. $y = 362.17\ x_1 + 2189.5$

$R^2 = 0.7241$

Where y: net profit for local potato consumption in Egypt (Euro), $x_1$: Compost rate (ton/ha) and $R^2$: coefficient of determination (linear regression).

7.4.2. $y = -872.33\ x_2 + 4839.6$

$R^2 = 0.8909$

Where y: net profit for local potato consumption in Egypt (Euro), $x_2$: Water regime (% of $ET_c$) and $R^2$: coefficient of determination (linear regression).

### 7.5. Effect of compost and water regime on net profit for potato exportation using soil mulching as follows:-

7.5.1. $y = 964.69\ x_1 + 4806$

$R^2 = 0.8549$

Where y: net profit for exportation (Euro), $x_1$: Compost rate (ton/ha) and $R^2$: coefficient of determination (linear regression).

7.5.2. $y = -1535\ x_2 + 10288$

$R^2 = 0.8889$

Where y: net profit for exportation (Euro), $x_2$: Water regime (% of $ET_c$) and $R^2$: coefficient of determination (linear regression).

In general and as a result of the triple interaction among the studied treatments, using drip irrigation either with soil mulching or not, 80 % of $ET_c$ as a water regime could be the best (crop coefficients ($K_c$) were 0.62, 0.83, 0.80, 0.76 and 0.62 for initial, development, mid-season, late-season and maturity stages of potato growth, respectively).

On the other hand, reducing drip irrigation water level at 60% of $ET_c$ in mulched soil that was treated with 36 ton $ha^{-1}$ of compost could be the most efficient for applying nutrients and potato crop production (crop coefficients ($K_c$) were 0.74, 0.92, 0.96, 0.87 and 0.71 for initial, development, mid-season, late-season and maturity stages of potato growth, respectively), where the highest efficiency among the studied treatments was obtained. Reducing the compost rate to 24 ton $ha^{-1}$ attained the highest net profit for local potato consumption and achieved the best significant net profit for exportation (crop coefficients ($K_c$) were 0.72, 0.84, 0.94, 0.87 and 0.62 for initial, development, mid-season, late-season and maturity stages of potato growth, respectively). Probably this combination of (60 % of $ET_c$ water regime + soil mulching + incorporating 24 ton $ha^{-1}$ of compost) could be the way to get the best soil and water management under drip irrigation technology using natural conditioner sources ( sugar cane wastes as mulch and compost).

## *8. SUMMARY*

Water is fast becoming an economical scare resource in many areas of the world, especially in arid and semi-arid regions. As the result of the ground water, is almost the single water resource in Kharga Oasis (the capital of New Valley Governorate), the Western Desert in Egypt, is very expensive either for the fixed cost or the running cost of well, which is necessary for reclaiming more areas of the desert. Also, to meet the demand of the growing population in Egypt by producing sufficient food, horizontal expansion should be enhanced thus high management is needed. There are many areas suggested for expansion in the Western Desert. These areas are sandy having poor soil properties.

Therefore, the objective of the present study is to achieve the best soil and water management in the Western Desert by saving irrigation water and to find out the best water economy, water use efficiency and net profit (net income) for potato local consumption and exportation under drip irrigation technology. The proper soil and water management (water regime, controlling of the evaporation process from the soil surface by mulching and improving hydrophysical and chemical properties of soil by applying compost) requires not only accurate determination of crop water requirements but also the determination of the accurate water amount that should be applied to get the highest output of each unit of water.

Split-split plot design field experiment with three replications for each treatment using potato as an indicator plant was carried out during the winter season 2005-2006 at the Agricultural Research Centre Farm, Kharga Oasis, Western Desert in Egypt. Three irrigation levels of water regime (100 %, 80 %, and 60 % of $ET_{c)}$ occupied to the main plots taking in the account that water regime of potato plant was calculated using local climate data in Western Desert and two treatments of soil covering (sugar cane wastes at the rate of 24 ton /ha)] assigned to the sub-plots, while sub-sub-split plots were occupied by compost rates (0, 12, 24, and 36 ton $ha^{-1}$).

Fertilizers for potato were added according the growth stage as the recommendation of Egyptian Ministry of Agriculture and Land Reclamation.

General effect of applying compost and soil mulching under drip irrigation regimes, also effect of interactions between them are collected in the following:-

***Growth and yield of potato crop***

Plant height, number of branches per plant and concentration of nitrogen, phosphorus and potassium in the plant were significantly raised by increasing compost rates up to 36 ton $ha^{-1}$. Moreover, increasing rate of compost considerably increased number of potato tuber per plant and tuber weight. Therefore, there were significant increments in average yield per plant and total yield $ha^{-1}$. Increments in potato yields due to applying 12, 24 and 36 ton compost $ha^{-1}$ were 33.4, 52.4, and 60.1 % over potato plants that didn't receive compost, respectively.

Mulching the soil with dried sugar cane wastes slightly increased plant height, while for the number of branches per plant such increase was significant. Moreover, soil mulching generally increases the values of nitrogen, phosphorus and potassium percentage in potato plant. These increments were insignificant comparing to that in the non-mulched soil.

Mulching considerably increases the values of potato weight. While average yield per plant and number of tubers per plant slightly decreased. Therefore total tuber yield was insignificantly reduced.

With regard to the impact of three irrigation water levels applied, i.e. 100 %, 80 % and 60 % of $ET_{crop}$, both plant height and number of branches per plant gradually decreased with increasing the amounts of irrigation water from 60 to 100% of the $ET_c$.

Regarding plant nutrient percentage, increasing applied water significantly decreased nitrogen and potassium percentages in the potato plant. While applying water irrigation level from 60 % of $ET_c$ to 80 % its insignificantly decreased phosphorus percentage, more added water to be 100 % of $ET_c$ significantly decreased it.

Increasing applied water irrigation level from 60 to 80% of the $ET_c$ increased number of tubers per plant then increasing water level to 100 % of the $ET_c$ decreased it. Average potato tuber weight or average yield per plant gradually decreased with increasing applied irrigation water from 60 to 100% of the $ET_c$. Accordingly, increments in total tuber yield $ha^{-1}$ for 80 and 60 % of the $ET_c$ were 32.33 % and 39.86 % compared to 100 % of the $ET_c$ water regime.

**With reference to the interaction between water regime and mulch**, data showed that the highest plants and number of branches per plant were achieved by 60 % of $ET_c$ of water regime in mulched soil while the shortest ones and the lowest number of branches were obtained under 100 % of $ET_c$ of water regime in the same mulched soil.

Moreover, the highest values of nitrogen, phosphorus and potassium percentages were determined in the plant tissue from (60 % of $ET_c$ of water regime + soil mulching) interaction. On the contrary, the greatest decrements in the concentration of the studied nutrients were found by (100 % of $ET_c$ of water regime + soil mulching).

Regarding number of potato tubers per plant, it increased by increasing water regime from 60 to 80 % of the $ET_c$ with mulch. Another increase in water regime to be 100 % of the $ET_c$ decreased it. Decreasing water regimes with mulch increased potato tuber weight and yield per plant. While increasing water regimes from 60 to 80 % of the $ET_c$ with mulch increased number of potato tubers per plant and then decreased by 100 % of the $ET_c$. Consequently, the highest value of total potato tuber yield (27.2 ton $ha^{-1}$) was achieved by 60 % of the $ET_c$ water regime in mulched soil.

**Concerning the interaction between water regime and compost**, the highest plants and its number of branches were obtained by the combination between 60 % its water regime and applying compost rate of 36 ton $ha^{-1}$. On the other hand, the shortest plants and the least number of branches were recorded without compost and applying compost rate of 36 ton $ha^{-1}$under 100 % of $ET_c$ of water regime.

As regards nitrogen, phosphorus and potassium percentages in the potato plant, decreasing irrigation water levels combined with increasing applied compost rates led to increase in nitrogen, phosphorus and potassium concentration in the plant. The maximum values of nitrogen, phosphorus and potassium percentages in the plant were obtained from the combination between (60 % of $ET_c$ of water regime + 36 ton $ha^{-1}$compost rate). In contrast none compost under 60 % of $ET_c$ of water regime the minimum nitrogen, phosphorus and potassium percentages in the plant were recorded.

Decreasing irrigation water levels combined with increasing applied compost rates led to increase in potato tuber weight and yield per plant except for the combination between 100 % of the $ET_c$ applied water and 36 ton compost $ha^{-1}$, it's also noticed that increasing irrigation water levels from 60 to 80 % of the $ET_c$ combined with increasing applied compost led to increase in number of potato tubers per plant and then its decrease by 100 % of the $ET_c$.

Accordingly the highest value of total tuber yield (32.2 ton $ha^{-1}$) was attained by applying 36 ton compost $ha^{-1}$and irrigating the soil by 60 % of $ET_c$. The lowest value of total tuber yield (15.4 ton $ha^{-1}$) was recorded from the soil that didn't receive compost and irrigated by 100 % of the $ET_c$.

**Regarding interaction between compost and mulch,** the highest values for mean plant height and mean number of branches per plant were attained from applying compost 36 ton $ha^{-1}$under soil covering. However, the lowest values were found without compost either with or without soil covering.

Increasing applied compost rates with soil covering significantly increased nitrogen, phosphorus and potassium concentration in the potato plant. The highest percentages of nitrogen, phosphorus and potassium were attained in the plants grown in mulched soil with applying 36 ton compost $ha^{-1}$. However, the lowest concentration of nitrogen and potassium were obtained in the same soil (with soil covering) that didn't receive compost, but the minimum percentage of phosphorus was obtained in both of non-mulched and mulched soils that weren't treated with compost.

Increment in application of compost with soil mulching significantly increased mean potato tuber weight and mean yield per plant hence total tuber yield. The highest values of potato tuber weight, yield per plant and total tuber yield (26.87 ton $ha^{-1}$) were achieved from compost rates at 36 ton $ha^{-1}$under soil covering. While the lowest yield was obtained in none mulched soil that wasn't treated with compost (16.96 ton $ha^{-1}$). With respect to number of potato tubers per plant, the maximum number was attained from compost rates at 36 ton $ha^{-1}$in non mulched soil. While the minimum number was obtained in mulched soil didn't receive compost.

**Concerning effect of the triple interaction among water regime, mulch and compost,** obtained results indicate that the triple interaction among water regimes, mulch and compost rates resulted in significant differences in all parameters of potato crop. The highest plants and its number of branches were obtained by the combination between (60 % of $ET_c$ water regime + soil mulching + applying compost rate of 36 ton $ha^{-1}$). On the other hand, the shortest plants and the lowest number of branches per plant were recorded by (without applying compost or with applying 36 ton $ha^{-1}$+ 100 % of $ET_c$ of water regime + mulched soil).

Highly negative effect for nitrogen percentage was registered under the interaction among (without compost + 100 % of $ET_c$ water irrigation level + mulched soil) which gave the minimum nitrogen percentage. Concerning phosphorus, highly negative effect was recorded for the interaction among (without compost + 60 % of $ET_c$ water irrigation level + non-mulched soil) which gave the lowest phosphorus percentage. On the other hand, the maximum nitrogen, phosphorus and potassium percentages were achieved by the combination between (60 % of $ET_c$ water regime + soil mulching + applying compost rate of 36 ton $ha^{-1}$).

The highest values for potato tuber weight and yield per plant thus total tuber yield (32.6 ton $ha^{-1}$) were obtained by the combination between (60 % of the $ET_c$ water regime+ soil mulching + applying compost rate of 36 ton $ha^{-1}$) but the best value for total tuber yield (30.72 ton $ha^{-1}$) was attained by the combination between (60 % of the $ET_c$ water regime + soil mulching + applying compost rate of 24 ton $ha^{-1}$). On the other hand, the lowest values were recorded without compost in non mulched soil for potato tuber weight and in mulched soil for average yield per plant and total tuber yield under 100 % of the $ET_c$ water regime.

***<u>Soil hydrophysical properties</u>***

Incorporating compost in the soil improved its hydrophysical properties through decreasing its bulk density, drainable pores, infiltration rate, hydraulic conductivity and mean diameter of soil pores. On the other hand compost increased its total porosity, void ratio, water holding pores and hence moisture retention (total holding capacity, field capacity and wilting percentages).

Soil mulching generally reduced soil bulk density, water transmitting properties (hydraulic conductivity and infiltration rate), therefore slightly increased total porosity, void ratio and hence increased moisture retention in the soil.

Increasing applied water to the soil insignificantly decreased its bulk density, its drainable pores, water holding pores, infiltration rate, and field capacity. On the other hand, soil void ratio, total porosity, hydraulic conductivity and mean diameter of soil pores were insignificantly increased.

***<u>Soil plant water relationships</u>***

Water economy and water use efficiency (kg $m^{-3}$ were significantly increased under all application rates of compost. By applying 0, 12, 24 and 36 ton compost $ha^{-1}$, water economy was recorded as 5.6, 7.7, 8.8 and 9.3 kg $m^{-3}$ respectively, while relevant values for water use efficiency were 7.4, 9.5, 10.2 and 10.4 kg $m^{-3}$ in sequence.

Mulching the soil led to an insignificant increase in water economy to be 7.88 and 7.92 kg $m^{-3}$ by the non-mulched and mulched soil, respectively. On the contrary; water use efficiency of the latter was lower than that of the former by 2.7 %.

Values of water economy were 4.75, 7.86, 11.08 kg $m^{-3}$ for the plants that irrigated by 100, 80 and 60 % of their $ET_{crop}$, respectively. The same is true with water use efficiency; its values were 5.66, 9.21 and 13.34 kg $m^{-3}$, respectively.

**With reference to the interaction between water regime and mulch**, decreasing water regimes with mulch increased water economy and water use efficiency. The highest values of water economy (11.34 kg $m^{-3}$) and water use efficiency (13.38 kg $m^{-3}$) were achieved under 60 % of the $ET_c$ of water regime in mulched soil.

**Concerning the interaction between water regime and compost**, applying 36 ton compost $ha^{-1}$ under 60 % of the $ET_c$ attained the highest values of water economy (13.4 kg $m^{-3}$) and water use efficiency (15.03 kg $m^{-3}$). It might be recognized that interaction (24 ton $ha^{-1}$compost rate under 60 % of the $ET_c$) achieved the best value of water use efficiency (14.9 kg $m^{-3}$).

**Regarding interaction between compost and mulch,** increasing applied compost rates with soil covering significantly increased water economy and water use efficiency. The highest values of water economy (9.49 kg $m^{-3}$) and water use efficiency (10.75 kg $m^{-3}$) were attained due to applying 36 ton compost $ha^{-1}$in non mulched soil. However, the lowest values were obtained from the same soil that didn't receive compost.

**Concerning effect of the triple interaction among water regime, mulch and compost,** the highest values for water economy( 13.62 kg $m^{-3}$) and water use efficiency ( 15.06 kg $m^{-3}$)were recorded by the combination between 60 % of the $ET_c$, soil mulching and applying compost rate at 36 ton $ha^{-1}$. However, the best values for water economy (12.56 kg $m^{-3}$) and water use efficiency (14.77 kg $m^{-3}$) were recorded by the combination between (60 % of the $ET_c$+ soil mulching and applying compost rate at 24 ton $ha^{-1}$)which achieved the best net profit values (4,520.29 and 9,896.29 Euro/ha) for local consumption and exportation, respectively.

The maximum crop coefficient ( $K_c$= 0.91) was obtained by the interaction between (80 % of $ET_c$ water regime + mulching the soil + applying compost rate at 36 ton $ha^{-1}$) but the interaction between (60 % of $ET_c$ water regime + mulching the soil + applying compost rate at 24 ton $ha^{-1}$) achieved 0.86.

***Fertilizer use efficiencies***

Incorporating compost in the soil clearly increased nitrogen, phosphorus and potassium fertilizers use efficiencies. On other hand soil mulching slightly decreased the values of nitrogen, phosphorus and potassium fertilizers use efficiencies for potato plants.

Regarding the triple interaction between water regimes, mulch and compost rates**,** the decrement in applied water with increasing applied compost rates increased nitrogen, phosphorus and potassium fertilizer use efficiencies in mulched soil and none mulched one.

***Economic analysis***

Incorporating compost in the soil significantly increase net profit (net income) of local consumption and exportation for potato crop compared to the soil that didn't receive compost except in incorporating compost at 36 ton $ha^{-1}$; net profit decreased for local consumption and insignificantly increased for exportation. Applying compost rate, at 24 ton $ha^{-1}$, gave the highest value for local potato consumption and the best value for exportation.

Relating to soil mulching, it is detected that mulching slightly decreased the values of net profit. Moreover, increasing applied water to the soil considerably decreased net profit for potato.

Regarding the triple interaction among compost, soil mulching and water regime, the increments in compost rates (excluding 36 ton $ha^{-1}$of compost for local potato consumption) associated with the decrements in water levels led to increments in net profit. The combination of (60 % of $ET_c$ water regime + mulching the soil + applying compost rate of 24 ton $ha^{-1}$) attained the best net profit for local potato consumption in Egypt and exportation.

## *9. RECOMMENDATIONS*

According to the obtained results for the triple interactions among the studied treatments (water regimes using drip irrigation technology, soil mulching and compost rates), it might be recommended for achieving the best potato tuber yield and water use efficiency and thus, the greatest net profit (net income) for potato crop in the Western Desert in Egypt, to be one of the following four treatments' combinations for soil and water management:

- When using drip irrigation technology alone, 80 % of $ET_c$ (3200 $m^3ha^{-1}$) could be noticed to be the best water regime.
- As for drip irrigation technology and soil mulching, it may be observed that the interaction between 80 % of $ET_c$ water regime + soil mulching was the best treatment.
- In regard to drip irrigation technology and application compost rates, it might be noticed that using the treatment of 80 % of $ET_c$ water regime + compost rate of 12 ton $ha^{-1}$ or the treatment of 60 % of $ET_c$ water regime + compost rate of 24 ton $ha^{-1}$was the best treatment.
- When using drip irrigation technology, soil mulching and application compost rates, it could be detected that reducing drip irrigation water level to 60 % of $ET_c$ in mulched soil that was treated with compost at 36 ton $ha^{-1}$ recorded the highest potato tuber yield, but reducing irrigation water level to 60 % of $ET_c$ in mulched soil that treated with compost rate at 24 ton $ha^{-1}$ attained the best water use efficiency and the highest net profit for local potato consumption in Egypt and achieved the best significant net profit for exportation.

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## *11. ANNEX*

### *11.1. __Sprinkler irrigation system__*

To increase crop production in keeping with the population growth, more area of land needs to be cultivated. This is promising only by using the sprinkler and drip irrigation systems instead of surface methods for certain crops and certain locations (Thool et al., 2003). It is estimated that the sprinkler irrigation system substantially reduces the use of water and the crop productivity increases. Suitability The sprinkler irrigation system is a very suitable method for irrigation on sloppy lands and on shallow soils. It is best suited to coarse sandy terrain where the percolation loss is more and where as a consequence, the frequency of irrigation required is more. The sprinkler irrigation system is also suitable in undulating terrain where land shaping is expensive or technically not feasible. The removal of fertile soil cover by land shaping is not advisable. Sprinkler irrigation system can also be adopted in hilly regions where plantation crops are grown. Crops suitable nearly all crops are suitable for sprinkler irrigation system except crops like paddy, jute, etc. The dry crops, vegetables, flowering crops, orchards, plantation crops like tea, coffee are all suitable and can be irrigated through sprinklers.

Other advantages

1. Fertilizers and pesticides can be effectively applied in split doses through sprinklers at little extra cost. This facilitates uniform fertilizer application and effective pest control.

2. The overall cost of labour is generally reduced.

3. Erosion of soil cover which is common in surface irrigation can be eliminated.

http://www.docstoc.com/docs/21611565/SPRINKLER-IRRIGATION-SYSTEM

#### *11.1.1. __Type of sprinkler systems__*

There are many types of Sprinkler systems available in the market. On the basis of the arrangement for spraying irrigation water, sprinkler systems are classified the following:

i) Rotating head system

ii) Perforated Pipe system

The rotating head system is more versatile and popular.

### *11.1.2.* ***Components of sprinkler irrigation system***

1. Water source - open well / tube well / bore well / canal etc.

2. Pumping unit - centrifugal, submersible

3. Sprinkler - main and lateral pipelines, riser pipe, sprinklers (nozzles)

4. Other minor accessories / fittings like reducers, elbows, valve opening tees, end tees, regulators and gauges, valves, filters, etc.

5. Fertilizer applicator

The selection of pump, pipe line, length, number of sprinklers, and their design depends upon soil, topography, climate, cropping pattern and command area.

### *11.1.3.* ***Management of sprinkler irrigation systems***

Efficient sprinkler systems are the result of good system design, proper irrigation scheduling, careful operation, and timely maintenance. Good sprinkle irrigation requires an understanding of soil-water-plant relationships and that irrigation timing and amount depends on soil water holding capacity, weather, and crop growth progress. Adequate system design, installation, proper operation and maintenance are important for realizing the benefits of sprinkler irrigation over the system lifetime **(Hill and Williams, 2002)**.

***Design***

Sprinkler irrigation designs that neglect prevailing field/crop characteristics and environmental factors can lead to poor system performance. Consequently, equipment should be field calibrated regularly to ensure that application rates and uniformity are consistent with values used during the system design and those given in manufacturers' specifications. Moreover, sprinkler irrigation design and management rules are very site specific, change with the irrigation materials, and most often rely on unstructured experiments and life-long professional experience. Hence, regular evaluation of irrigation systems is of essence to the maintenance of the systems for optimal performance at the designed parameters **(Osei, 2009 ; Ascough and Kiker, 2002)**.

**Hill and Barnhill (2001**) showed that a well designed sprinkler system applies water uniformly to the soil surface and is capable of applying enough water to meet the peak demands of the crop without producing excess runoff. Good design considers such factors as pressure; nozzle size and spacing; wind, air temperature and humidity (day versus night); soil intake rate; crop rooting depth and water use rates. The flow rate from a sprinkler nozzle depends upon nozzle size and water pressure.

**Good sprinkle irrigation requires (Hill and Drake, 2002):**

• Understanding of soil-water-plant Relationships

• Proper irrigation timing and amount depends on soil water holding capacity, weather, and crop growth progress

• Adequate Design and Installation

• Proper Operation and Maintenance

• Dedication and Commitment of Resources to Manage

Efficient sprinkler irrigation requires applying the right amount of water as evenly or uniformly as possible. Applying the right amount of water, in turn, requires knowing the soil moisture depletion, the application rate, and the depth applied **(Hanson.1993).**

### *11.1.4.* ***Improving sprinkler system performance***

The performance of a sprinkler system can be improved by the following measures **(Hanson.1993)**:

1. Know the application rate and average depth applied.
2. Avoid over irrigating. Over irrigation means applying water in excess of the soil moisture depletion in the parts of the field receiving the least amount of water. Reduce overirrigation by decreasing the set time.
3. Irrigate during low wind periods (wind speed of less than 10 mi/h). Sprinkler uniformity is greatly reduced at wind speeds greater than 10 or 15 mi/h.
4. Offset lateral locations to improve seasonal uniformity. In offsetting, the lateral locations of the current irrigation are midway between the lateral locations of the previous irrigation.
5. Use the same nozzle size throughout the irrigation system. Mixing nozzle sizes results in non-uniform application rates.
6. Use flow-control nozzles for excessive pressure variations. Pressure variations of more than 20 percent between the pressure of the first nozzle (closest to the pump) and last nozzle will cause non-uniform application rates. Flow-control nozzles reduce the variability in

application rate caused by pressure variability. Flow-control nozzles are sized according to their discharge rates (gal/min).

7. Repair leaks in the irrigation system and replace or repair malfunctioning nozzles.

8. Prevent crop interference by using properly sized risers.

9. Maintain adequate pressure by adjusting the pump impeller (semi open impellers), repairing or replacing a worn pump.

### *11.2. <u>Drip irrigation :-</u>*

#### *11.2.1. <u>Advantages of drip irrigation(Hartz, 1999;Lamont et al., 2002):</u>*

1. Smaller water sources can be used because trickle irrigation may require less than half of the water needed for sprinkler irrigation.
2. Lower operating pressures mean reduced energy costs for pumping.
3. High levels of water use efficiency are achieved because plants can be supplied with more precise amounts of water.
4. Disease pressure may be less because plant foliage remains dry.
5. Labor and operating costs are generally less, and extensive automation is possible.
6. Water applications are made directly to the plant root zone. No applications are made between rows or other non-productive areas, resulting in better weed control and significant water savings.
7. Field operations, such as harvesting, can continue during irrigation because the areas between rows remain dry.
8. Fertilizers can be applied efficiently through the drip system.
9. Irrigation can be done under a wide range of field conditions.
10. Compared to sprinkler irrigation, soil erosion and nutrient leaching can be reduced.

Hoffman and Martin (1993) mention that advantages of micro irrigation are less wetted surface area that reduces evaporation and weed growth, and improved application uniformity.

#### *11.2.2. <u>Disadvantages and limitations of drip irrigation (Lamont et al., 2002):</u>*

1. Initial investment costs per acre may be more than other irrigation options.

2. Management requirements are somewhat higher. Delaying critical operation decisions may cause irreversible crop damage.

3. Frost protection is not possible with drip systems; if this is needed, sprinkler systems are necessary.

4. Rodent, insect, and human damage to drip lines are potential sources of leaks.

5. Water filtration is necessary to prevent clogging of the small emitter holes.

6. Compared to sprinkler irrigation, water distribution in the soil is restricted.

### *11.2.3.* ***Drip irrigation system components***

A drip irrigation system has six major components (Lamont et al., 2002) as exposed in figure (80):

**1. Delivery system**

• Mainline distribution to field

• Sub-mainline (header line)

• Feeder tubes or connectors

• Drip lines

**2. Filters**

• Sand

• Screen

**. Pressure regulators**

• Fixed outlet

• Adjustable outlet

**4. Valves or gauges**

**fig. (80): Sand filter, pump, and fertigation unit (Lamont et al., 2002)**

**5. Chemical injectors**

• Positive displacement injectors

• Pressure differential injectors

• Water-powered injectors

**6. Controllers:** • Manual • Computer

### *11.3. Agriculture in Germany*

Agricultural irrigation in Germany aims to compensate precipitation deficits during the vegetation period with artificial water supplies in order to improve and save crop yield and crop quality. In Germany mainly irrigation is applied to areas of intensive agricultural and horticultural activities with annual precipitation rates of less than 700 mm. Sprinkler systems are the main irrigation methods, which generally depend on groundwater. The annual amount of irrigation water varies between 80 and 150 mm or between 425 and 800 million $m^3$ per year, respectively (GECID, 2012 available online).

EU- report, (2000) found that agriculture in Germany is highly varied, reflecting its diverse topography and climatic conditions. In the north and east there are large expanses of flat land that is well suited to arable cultivation. In the centre and south, there are more hills and mountain ranges and it is here that the main areas of pastoral agriculture are found, as well as more specialised crops such as vines. Water supplies are generally adequate for agriculture in most areas.

Martin Frielinghaus (2002) showed that the agricultural use of slope land increases the appearance of water erosion. In Germany altogether 28% of the arable lands are endangered through water erosions. To decrease the erosion danger in maize, sugar beets, and occasionally also at cereals direct seed in dead plant residues (mulch), combined with non plough soil tillage is used more and more. Especially in low range mountains the drizzling-irrigation of spring water on grassland was wide spread in former times. Irrigation is an important instrument for stabilization and increasing yields. However, irrigation water is only in limited quantities available. Because of these limited water quantities, water saving irrigation systems is needed. One method is the transition of basin irrigation to sprinkler systems. Sprinkler irrigation requires no levelling of the irrigation farmlands.

Surveys of the German Sprinkler Association undertaken in 2001 indicate that about 500 000 ha are equipped for sprinkler irrigation in Germany. An area of about 5 000 ha is under micro irrigation (mainly drip irrigation in vineyards). In the north-eastern part of the country there are about 600 000 ha of equipped lowlands. Combined drainage / subsurface irrigation facilities were installed there to manage peat soils and groundwater near sandy sites. Surface irrigation methods are not used anymore. Irrigation is mainly practiced on arable land and in most irrigation areas only specific crops in a crop rotation are irrigated (e.g. potatoes, sugar beets, maize, and vegetables) (FAO, 2011).

There are two main types of irrigation in Germany (EU- report, 2000):

Type 1: uses sprinklers with pressure and is mainly groundwater sourced. It is applied to semi intensive or intensive crop types in the form of support irrigation (short periods during the season). The trend for this type of irrigation is stable.

Type 2: also uses sprinklers with pressure but is surface sourced (both in situ and transported over long distances). It is applied to semi-intensive to intensive crop types in the form of support irrigation (short periods during the season). The trend for this type of irrigation is increasing.

### *11.3.1. **The challenges and the future agriculture in Germany***

Although Germany had the third largest utilized agricultural area in the European Union in 2010. The used agricultural area in Germany continued to decrease over the last few years. As reported by the Federal Statistical Office (DESTATIS, 2011b), the agricultural area used by holdings was just about 16.8 million hectares in 2011, which is 47% of the total area of Germany, while was 17,024, 16.95 and 17.3 million hectares in 2005, 2007 and 1995, respectively (DESTATIS, 2012a).

Accordingly, the total area equipped for irrigation in Germany is 485000 ha in 2009 while 496 871 ha in 2001 and 531,000 ha in 1994. The main reason for this significant decrease is the abandonment of many big irrigation facilities in the new Lands. Also, irrigation in equipped lowlands was neglected because it was reported, that operation and maintenance of the subsurface irrigation systems were drastically reduced during the transformation process of irrigated agriculture in Eastern Germany (EU- report, 2000; FAOSTAT, 2012b; FAO, 2012).

GGA-report (2010) showed that recreational and transport areas are spreading at the expense of agricultural and natural areas, so that the availability of land is presently in a downward trend. Not only in Germany, but worldwide areas useable for the production of foods and agricultural commodities are shrinking considerably. The objective of the Federal Government in Germany is to reduce land consumption, to preserve the priority of securing the food supply and to retain valuable natural areas. GGA-report (2010) mentioned that sustainable management and ecologically compatible agriculture, particularly organic farming, are objectives that are supported through financial assistance. In specialized legislation the Federal Government has set down principles of good practice in agriculture. The future viability of agriculture relies heavily on the political framework. A highly productive agricultural, forestry and fisheries industry that works in keeping with the basic principle of sustainability is the guiding principle of agricultural policy. In detail,

- Agriculture must be able to serve as the foundation for the earnings and prosperity of farmers.
- Agriculture must supply foods of high quality and raw materials for energy and industry.
- Agriculture must preserve nature and the environment for coming generations.

### ***11.3.2. <u>Institutional arrangements</u>***

Water management is the responsibility of the Lands, which have established water associations. Since irrigated agriculture is not very extensive, general water policies tend to override more specific policies that pertain exclusively to the agricultural sector. Traditionally, water prices have been based on the costs of extracting water from the natural cycle, and of water treatment and transportation. Until Baden-Wuerttemberg established a "water tax" in 1988, water remained significantly undervalued. Since then, other Lands have followed suit, and water taxation has become more common. However, these water taxes deviate from the commonly-accepted definition of water charges for two reasons. Firstly, they are generally levied only in cases where a permit or licence is required. Since water metering in the agricultural sector is not common in Germany, some estimates show that the allotted volumes as stated in licences deviate substantially from the actual abstractions carried out by licensees. Secondly, revenues collected through water taxes have often been used to compensate farmers for restrictions on fertilizer use in vulnerable areas. There are also tax rebates for those farmers who can provide evidence of being financially impaired by the tax. However, these rebates are conditional on farmers implementing water-saving strategies, and on using surface instead of ground water sources (EU- report, 2000).

## Table (49): Germany Fact Sheet (FAO, 2011)

| Land and Population | Year | Value | Unit |
|---|---|---|---|
| **Area** | | | |
| Country total area | 2008 | 35 711 | 1 000 ha |
| Cultivated area | 2008 | 12 133 | 1 000 ha |
| **Population** | | | |
| Total population | 2008 | 82 264 | 1 000 |
| Population density | 2008 | 230.4 | inhab/km² |
| Rural population | 2008 | 21 703 | 1 000 |
| Economically active population in agriculture | 2008 | 719 | 1 000 |
| **Water Resources (WR)** | **Year** | **Value** | **Unit** |
| **Long-term average annual precipitation** | | | |
| Depth | | 700 | mm/year |
| Volume | | 250 | km³/year |
| **Long-term average annual renewable WR** | | | |
| Internal (IRWR) | | 107 | km³/year |
| External (ERWR) | | 47 | km³/year |
| Total (TRWR) | | 154 | km³/year |
| Dependency ratio | | 30.52 | % |
| TRWR per capita | 2008 | 1 872 | m³/year |
| **Total dam capacity** | 2008 | 4 | km³ |
| **Water Withdrawal** | **Year** | **Value** | **Unit** |
| **By sector** | | | |
| Agricultural | 2007 | 0.081 | km³ |
| Municipal | 2007 | 5.128 | km³ |
| Industrial | 2007 | 27.09 | km³ |
| **Total** | 2007 | 32.3 | km³ |
| Total water withdrawal per capita | 2007 | 392.3 | m³ |
| **By source** | | | |
| Surface water withdrawal | 2007 | 26.48 | km³ |
| Groundwater withdrawal | 2007 | 5.825 | km³ |
| **Total freshwater withdrawal** | 2007 | 32.3 | km³ |
| Desalinated water produced | 2007 | 0 | km³ |
| Reused treated wastewater | | - | km³ |
| **Pressure on water resources** | | | |
| Total freshwater withdrawal as percentage of ARWR | 2007 | 20.97 | % |
| Agricultural water withdrawal as percentage of ARWR | 2007 | 0.0526 | % |
| **Irrigation and Drainage** | **Year** | **Value** | **Unit** |
| **Area equipped for irrigation** | | | |
| Full control irrigation | 2000 | 485 | 1 000 ha |
| surface irrigation — 1 000 ha | | | |
| sprinkler irrigation — 1 000 ha | | | |
| localized irrigation (1991) — 1.85 — 1 000 ha | | | |
| Equipped lowland areas | 2000 | 0 | 1 000 ha |
| Spate irrigation | 2000 | 0 | 1 000 ha |
| **Total area equipped for irrigation** | 2000 | 485 | 1 000 ha |
| As percentage of cultivated area | 2002 | 4.043 | % |
| Actually irrigated | | - | 1 000 ha |
| **Other agricultural water managed area** | 1998 | 0 | 1 000 ha |

Notes: 1 km³ = $10^9$ m³ = 1 000 million m³; 1 ha = 1 hectare = 10 000 m²

Generated: 13 May 2011 at 19:42 CEST http://www.fao.org/nr/aquastat/

http://www.fao.org/nr/water/aquastat/data/factsheets/aquastat_fact_sheet_deu_en.pdf

### *11.4. Agriculture in Egypt:-*

In 2009 agricultural area was 3689000 ha (3.7 % of total area in Egypt) while total area equipped for irrigation was 365000 ha (FAOSTAT, 2012 (available online). FAO (2009) reported that irrigation potential is estimated at 4 420 000 ha. The total area equipped for irrigation was 3 422 178 ha in 2002; 85 percent of this area is in the Nile Valley and Delta. Rainwater harvesting is practised in about 133 500 ha in Matruh and North Sinai. All irrigation is full or partial control irrigation. Surface irrigation was practised on 3 028 853 ha in 2000, while 171 910 ha were under sprinkler irrigation and 221 415 ha under localized irrigation (fig. 81). Surface irrigation is banned by law in the new reclaimed areas, which are located at the end of the systems, and are more at risk of water shortage. Farmers have to use sprinkler or drip irrigation, which are more suitable for the mostly sandy soil of those areas.

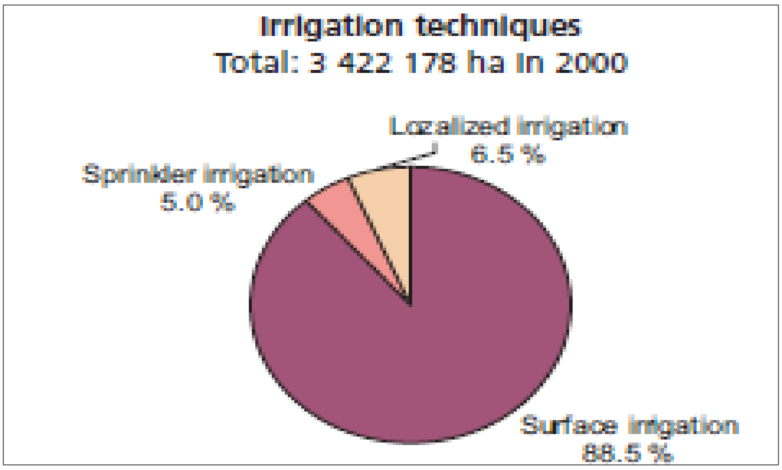



**Fig.(81): irrigation technique in Egypt (FAO, 2005)**

#### *11.4.1. Water resources*

FAO (2009) reported that the River Nile is the main source of water for Egypt, with an annual allocated flow 55.5 $km^3$/year under the Nile Waters Agreement of 1959. Internal renewable surface water resources are estimated at 0.5 $km^3$/yr. This brings total actual renewable surface water resources to 56 $km^3$/yr. Internal renewable groundwater resources are estimated at 1.3 $km^3$/yr. The overlap between surface water and groundwater being considered negligible, the total actual renewable water resources of the country are thus 57.3 $km^3$/yr. The Nubian Sandstone aquifer located under the Western Desert is considered an important groundwater source, but this is fossil groundwater. The main source of internal recharge is percolation from irrigation water in the Valley and the Delta.

### *11.4.2. Water use*

Total water withdrawal in 2000 was estimated at 68.3 $km^3$. This included 59 $km^3$ for agriculture (86 percent), 5.3 $km^3$ for municipalities (8 percent) and 4.0 $km^3$ for industry (6 percent (fig. 82). Apart from that, 4.0 $km^3$ were used for navigation and hydropower.

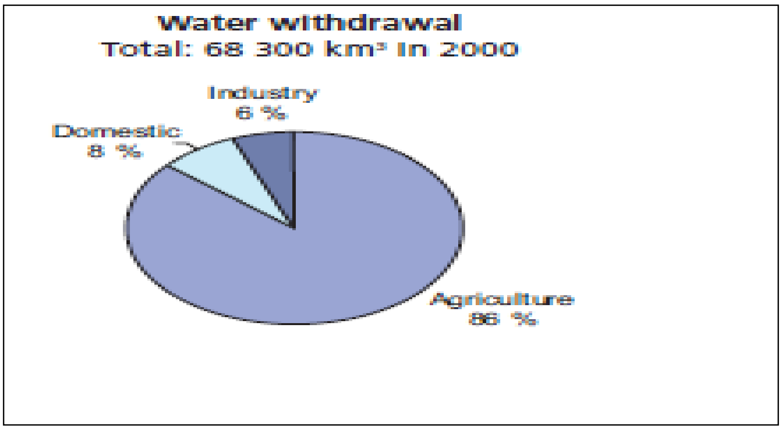


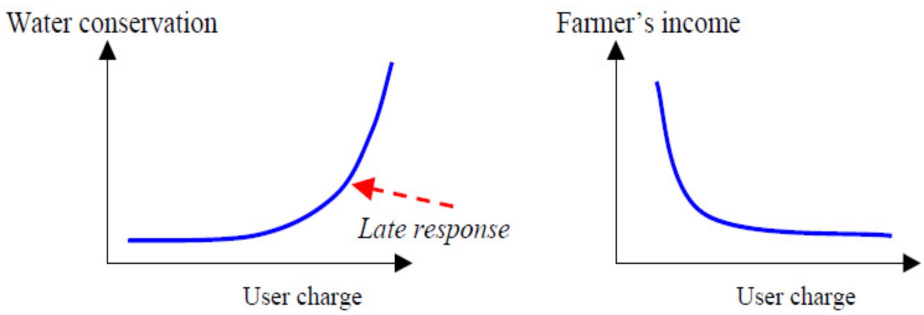

**Fig.(82): Water withdrawal in Egypt (FAO, 2005)**

Reuse of agricultural drainage water, returned to the rivers, in irrigation amounted to 4.84 $km^3$/yr in 2001/02. Of the 2.97 $km^3$/yr of treated wastewater, 1.5 $km^3$/yr is reused for irrigation, while the rest is pumped into main drains where it mixes with drainage water and is then used for irrigation. Treated wastewater is usually used for landscape irrigation of trees in urban areas and along roads (FAO, 2005).

### *11.4.3. Financing the Water Sector*

The Minister of Water Resources and Irrigation in Egypt (2005) has reported that present and future policies are likely to seek primary financing of the water sector only through three principal sources: sovereign sources and general-tax system, agricultural user-fees, and municipal/industrial user-fees. Almost 90% of the development, operation and maintenance (O&M), costs of water services in Egypt are funded by public sources. The public financing of O&M in the irrigation sector amounts to about 4% of the total public recurrent expenditures. The entire budget of MWRI is mainly allocated for the administration of irrigation and drainage networks in Egypt that serves all water-use sectors. The irrigated agriculture sub- sector consumes about 85% of the budget of MWRI while 10% are devoted to services for the water supply and sanitation sector subsector, and 5 % attributed to the industrial sector.

Malashkhia (2003) and Perry (2001) showed that in Egypt, the price required to induce a 15 percent fall in demand for water would have reduced farm incomes by 30 percent. The main reason behind this is the low prices. The elasticity of demand shows positive correlations to the price level (fig.83**)**. The elasticity increases with increased levels of user charge but it directly affects the income of farmers and impact is obviously negative. Therefore, there is very little change in consumer behaviour as response to the water charges but very big changes in income levels.




**a)** **b)**

**Fig. (83): a) Price-consumption elasticity graph b) Behavioural Patten of Farmer's income with regard of user charge (Perry, 2001)**

### *11.4.4. <u>Future water use in Egypt</u>*

The challenges facing the water sector in Egypt are enormous and require the mobilization of all resources and the management of these resources in an integrated manner. This is especially true as the amount of available water resources is fixed, meanwhile water demands continue to grow in the years ahead due to population growth, increased food demand, expansion and modernization of the industrial base, and improved standards of living (The Minister of Water Resources and Irrigation in Egypt, 2003) .

Oosterbaan (1999) mentioned that due to the re-allocation of Nile waters to the new irrigation developments (horizontal expansion), the availability of the presently irrigated lands will be reduced to about 90% of the original supply, and the existing net availability of irrigation water would drop from 4900 to 4400 billion $m^3$/year per feddan. To mitigate the decrease, water savings would have to be realized through improvement of irrigation efficiencies and reduction of irrigation water losses within the presently irrigated lands.

### *11.4.5.* ***Potato production in Egypt***

The potato is the 5th most important crop in the world. It is nutritious and highly productive, has a good value when sold, and is an effective cash crop for a developing country that has both local and export markets. This is the case in Egypt, where agriculture accounts for 28% of the national income. Almost 50% of the country's work force is dependent on the agricultural sub sector. Rising population and the resulting increase in domestic demand for agricultural products are putting pressure on agricultural exports (Dave, 2003).

FAOSTAT (2008) announced that since 1961, Egypt's irrigated potato production - concentrated in the Nile River Delta in the north - has expanded at a rate of more than 5 percent a year. Between 1990 and 2007, annual output rose from 1.6 million tonnes to some 2.6 million tonnes, making Egypt Africa's No. 1 potato producer. Egypt also ranks among the world's top potato exporters - in 2004, exports totalled more than 380 000 tonnes of fresh potatoes and 18 000 tonnes of frozen potato products, destined mainly for markets in Europe.

## 12. Declaration of originality

I, Nahla Abdel-Fattah Hemdan Mohamed, hereby declare that this dissertation entitled **“Irrigation Systems: Overview about Technology & Management, Results of Experiments on Drip Irrigation in Egypt”** is my own original work and that all sources that were used have been properly acknowledged and referenced in the text. This work has not been submitted elsewhere in any form as part of another dissertation.

……………………………. Berlin, 2013

Nahla A. Hemdan Mohamed